BENEFIT-COST ANALYSIS OF ENVIRONMENTAL REGULATION: CASE STUDIES OF HAZARDOUS AIR POLLUTANTS

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Regulating toxic chemicals is highly controversial, yet it promises to be a major task confronting an industrial society. Increasing attention to toxic substances reflects in part recent growth in the number and quantity of man-made chemicals. As controls over the conventional pollutants take effect, toxic substances move to center stage in the political arena. This increased attention also stems from the fact that many of the statutes and regulatory procedures developed for the conventional pollutants are ill-suited to the new substances.

The Administrator of the Environmental Protection Agency, William Ruckelshaus, has urged Congress to reconsider the present statutory framework for regulating toxic air pollutants.[1] EPA may shift its regulatory strategy from the identification of specific control technology and

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Financial support for this article provided by the U.S. Environmental Protection Agency under Cooperative Agreement CR-809802-01-0 with the Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University; Harvard School of Public Health, Interdisciplinary Programs in Health, U.S. Environmental Protection Agency Grant #CR-807809; and The Alfred P. Sloan Foundation Program in Environmental Health.

Although the research described in this report has been funded by the agencies listed above, it has not been subjected to their peer and administrative reviews, may not reflect the views of those agencies, and no official endorsement should be inferred.

1. *See* Statement by W. Ruckelshaus, Administrator of the EPA, Before the Subcomm. on Oversight & Investigations of the House Comm. on Energy & Commerce 10–11 (Nov. 7, 1983) (listing the specific problems experienced in implementing section 112) [hereinafter cited as Statement by Ruckelshaus].

evaluation of the industry's ability to afford controls[2] to a strategy that weighs the trade-offs between control costs and risk reduction.[3]

This article evaluates alternative methods of integrating benefit-cost considerations into the regulation of toxic substances. The use of benefit-cost considerations in this context is highly controversial and widely debated. The debate, however, has incorporated little or no reference to specific decisions made by environmental policy makers.[4] Proponents of benefit-cost analysis point to the general virtues of explicit evaluation of benefits and costs. Critics, on the other hand, stress the philosophical difficulties involved in making judgments about life and death[5] or the practical difficulty of estimating the costs and benefits of control.[6] These broad debates do not consider what is at stake in particular circumstances and, indeed, whether those who assess the scientific evidence very differently might find much common ground in actual regulatory decisions. This article attempts to fill that gap by considering three toxic pollutants — benzene, coke oven emissions, and acrylonitrile. All three pollutants are currently considered targets for control under section 112 of the Clean Air Act.[7]

This article focuses on the ideas that benefit-cost principles can help to identify regulatory alternatives and that benefit-cost analysis can yield widely accepted policy recommendations despite large uncertainties in many parameter estimates. Critics caricature benefit-cost analysis as a mindless toting up of costs and benefits, but benefit-cost principles are

2. *Id.* at 20.
3. *See* W. Ruckelshaus, Administrator of the EPA, Science, Risk and Policy 10 (June 22, 1973) (speech to the National Academy of Sciences). *See also* W. Ruckelshaus, Administrator of the EPA, Risk in a Free Society (Feb. 18, 1984) (speech at Princeton University); speech by J. Cannon, EPA Asst. Administrator for Air and Radiation, to the Natural Resources Law Section of the American Bar Association (Mar. 10, 1984).
4. *See, e.g.*, Crandall, *The Use of Cost-Benefit Analysis in Regulatory Decisions*, in MANAGEMENT OF ASSESSED RISK FOR CARCINOGENS 99–107 (W. Nicholson ed. 1981) (defending the general applicability of benefit-cost analysis to regulatory decisionmaking); Harrison, *Cost-Benefit Analysis and the Regulation of Environmental Carcinogens*, in MANAGEMENT OF ASSESSED RISK FOR CARCINOGENS 109–22 (W. Nicholson ed. 1981) (evaluating the advantages of using benefit-cost principles in regulating carcinogens); Ashford, *Alternatives to Cost-Benefit Analysis in Regulatory Decisions*, in MANAGEMENT OF ASSESSED RISK FOR CARCINOGENS 129–37 (W. Nicholson ed. 1981) (discussing the general limitations of benefit-cost analysis in regulatory decisionmaking).
5. *See, e.g.*, S. KELMAN, WHAT PRICE INCENTIVES? 27–88 (1981) (summarizing the ethical concerns involved in using the market for pollution control); Kelman, *Cost-Benefit Analysis and Environmental, Safety, and Health Regulation: Ethical and Philosophical Considerations*, in COST-BENEFIT ANALYSIS AND ENVIRONMENTAL REGULATIONS: POLITICS, ETHICS, AND METHODS 137–54 (D. Swartzman, R. Likoff & K. Croke eds. 1982).
6. *See, e.g.*, Ashford, *supra* note 4, at 129–37.
7. 42 U.S.C. § 7412 (Supp. V 1981). Although this article provides background information on the provisions and history of section 112 to place the specific case studies discussed in context, its analysis is not restricted to regulatory alternatives permitted by the current statute. Thus, some of the alternatives that it considers might require statutory changes.

more properly viewed as a framework for exploring opportunities to increase health and other benefits or reduce unnecessary costs. The crucial concept is *marginalism*. Given an existing regulation, benefit-cost analysis identifies marginal changes that increase benefits more than costs, or decrease costs more than benefits.[8]

Critics argue that the data on benefits and costs of regulatory alternatives are simply too uncertain to use risk assessment or benefit-cost results in policymaking.[9] In some cases, however, all plausible estimates of the parameters lead to the same policy recommendation. Thus, the results in such cases remain robust with respect to uncertainty. Two of the three case studies evaluated in this paper fall in this category.[10] Uncertainty, therefore, should not serve to dismiss out-of-hand benefit-cost analysis in environmental regulation.

The first Part of this article discusses section 112 of the Clean Air Act, which provides the framework for regulating the three case-study pollutants.[11] Part II presents the three case studies and includes an analysis of regulatory alternatives for the three pollutants.[12] The next Part summarizes the uncertainties in calculating regulatory benefits, and the effect of those uncertainties on policy recommendations.[13] Finally, Part IV outlines the overall conclusions derived from examining the case studies.[14]

I. REGULATORY CONTROLS

A. *Section 112 of the Clean Air Act*

Section 112 provides the statutory authority for regulating "hazardous" air pollutants emitted from stationary sources.[15] That section reflects he need to regulate hazardous pollutants outside the complex framework

8. The technology-based standards that the EPA has promulgated provide a basis for valuating the benefits and costs of those standards and for a detailed investigation of egulatory alternatives.
9. *See, e.g.*, Hurter, Tolley & Fabian, *Benefit-Cost Analysis and the Common Sense f Environmental Policy*, in COST-BENEFIT ANALYSIS AND ENVIRONMENTAL REGULAIONS: POLITICS, ETHICS, AND METHODS 92–99 (D. Swartzman, R. Likoff & K. Croke eds. 82) (discussing the potential sources of uncertainty in comparing the benefits and costs environmental programs).
10. *See infra* text accompanying note 109. *See also infra* Table 1.
11. *See infra* notes 15–56 and accompanying text.
12. *See infra* notes 57–140 and accompanying text. A more detailed analysis of these se studies has been presented in an earlier manuscript. Haigh, Harrison & Nichols, nefits Assessment and Environmental Regulation: Case Studies of Hazardous Air Polants (July 1983) (unpublished manuscript available upon request from the authors).
13. *See infra* notes 141–220 and accompanying text.
14. *See infra* notes 221–228 and accompanying text.
15. 42 U.S.C. § 7412 (Supp. V 1981).

of ambient standards, state implementation plans, and new source performance standards established for the more ubiquitous "criteria" pollutants.[16] The Act defines a hazardous air pollutant as one "to which no ambient air quality standard is applicable and which in the judgment of the Administrator causes, or contributes to, air pollution which may reasonably be anticipated to result in mortality or an increase in serious irreversible, or incapacitating reversible, illness."[17] Section 112 requires the EPA Administrator to establish a list of hazardous air pollutants and, within 180 days of listing a substance, to set emission standards for sources "at the level which . . . provides an ample margin of safety to protect the public health."[18]

The language of section 112 emerged as a compromise from the House-Senate conference committee on the Clean Air Act amendments of 1970.[19] The House bill proposed basing national emission standards for hazardous air pollutants on technological and economic feasibility.[20] In contrast, Senator Edmund Muskie and his supporters in the Senate

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> [I]t is urgent that Congress adopt new clean air legislation which will make possible the more expeditious imposition of specific emission standards both for mobile and stationary sources and the effective enforcement of such standards by both State and Federal agencies . . . . Therefore, particular attention must be given to new stationary sources which are known to be either particulary large-scale polluters or where the pollutants are extrahazardous.

H.R. Rep. No. 1146, 91st Cong., 2d Sess. 5, *reprinted in* 1970 U.S. Code Cong. & Ad. News 5356, 5360–61.

17. 42 U.S.C. § 7412 (Supp. V 1981).

18. Section 112(b) provides that:

> (1)(A) The administrator shall, within 90 days after December 31, 1970, publish (and shall from time to time thereafter revise) a list which includes each hazardous air pollutant for which he intends to establish an emission standard under this section.
> (B) Within 180 days after the inclusion of any air pollutant in such list, the Administrator shall publish proposed regulations establishing emission standards for such pollutant together with a notice of a public hearing within thirty days. Not later than 180 days after such publication, the Administrator shall prescribe an emission standard for such pollutant, unless he finds, on the basis of information presented at such hearings, that such pollutant clearly is not a hazardous air pollutant. The Administrator shall establish any such standard at the level which in his judgment provides an ample margin of safety to protect the public health from such hazardous air pollutant.

Id. § 7412(b).

19. H.R. Rep. No. 1783, 91st Cong., 2d Sess. 10–12, 45–47, *reprinted in* 1970 U.S. Code Cong. & Ad. News 5356, 5378–79.

20. The relevant section provided that:

> (a) For the purpose of preventing the occurrence of significant new air pollution problems arising from or associated with any class of new stationary sources which, because of the nature or amount of emissions therefrom, may contribute substantially to endangerment of the public health or welfare, the Secretary shall from time to time by regulation, giving appropriate consideration to technological and economic feasiblity, establish standards with respect to such emissions . . . .
> (b) Such emission standards shall provide that —
> (1) If such emissions are extremely hazardous to health, no new source of such emissions shall be constructed or operated, except where (and subject to such conditions as he deems necessary and appropriate) the Secretary makes a specific exemption with respect to such construction or operation.
> (2) In the case of other emissions, any new source of such emissions shall be designed and equipped to prevent and control such emissions to the fullest extent compatible with the available technology and economic feasibility, as determined by the Secretary.

H.R. Rep. No. 1146, 91st Cong., 2d Sess. 35 (1970).

favored a zero-discharge requirement, which would have applied to fewer pollutants than the House bill.[21] The final language of the section, however, refers neither to technological feasibility nor to zero discharges.[22] This suggests that, while the conference committee expected health considerations to determine standards, it did not expect health protection to require the absolute elimination of all hazardous emissions.

B. Dilemmas in Implementation

EPA's regulatory activity under section 112 over the past thirteen years has been modest.[23] Emission standards have been promulgated for

21. Bonine, *The Evolution of 'Technology-Forcing' in the Clean Air Act*, [Monograph No. 21] 6 Env't Rep. (BNA) 7 (July 25, 1975). The Senate report indicated its determination "that existing sources of pollutants should meet the standard of the law or be closed down, and in addition, that new sources should be controlled to the maximum extent possible to prevent atmospheric emissions." S. Rep. No. 1196, 91st Cong., 2d Sess. 2–3 (1970). Later, however, the report says that "[i]n writing a relatively restrictive definition of hazardous agents, the Committee recognized that a total prohibition on emissions is a step that ought to be taken only where a danger to health, as defined, exists." *Id.* at 20.

The bill provided in part that:

> (a) (1) The Secretary shall, within ninety days after the enactment of this section and from time to time thereafter, publish in the Federal Register a list of those air pollution agents or combination of such agents which available material evidence indicates are hazardous to the health of persons and which shall be subject to a prohibition or emission standard established under this section.
> (2) Within one hundred and eighty days after the publication of such list, or revision thereof, the Secretary, in accordance with section 553 of title 5 of the United States Code, shall publish a proposed prohibition and a notice of a public hearing within thirty days. As soon as possible after such hearing, but not later than six months after such publication, the Secretary shall promulgate such prohibition, unless, based upon a preponderance of evidence adduced at such hearing, he finds within such period and publishes his finding —
> (A) that such agent is not hazardous to the health of persons; or
> (B) that a departure from such prohibition for stationary sources will not be hazardous to the health of persons.
> (3) If the Secretary finds under paragraph (2)(A) of this subsection that such agent is not hazardous to the health of persons, he shall immediately publish an emissions standard in accordance with the procedures established under section 114 of this Act.
> (4) If the Secretary finds under paragraph (2)(B) of this subsection that a departure from such prohibition for any stationary source will not be hazardous to the health of persons, he shall immediately promulgate an emission standard for such agent or combination of agents from any such stationary source to protect the health of persons.

Id. at 95–96.

22. *See supra* note 18.

23. *See generally* Doniger, *Federal Regulation of Vinyl Chloride: A Short Course in Law and Policy of Toxic Substances Control*, 7 Ecology L.Q. 497, 565–85 (1978); Currie, *Direct Federal Regulation of Stationary Sources Under the Clean Air Act*, 128 U. Pa. L. Rev. 1389 (1980) (generally discussing regulatory activity under section 112).

only four substances: beryllium, asbestos, mercury, and vinyl chloride.[24] The EPA has listed three additional substances: benzene, radionuclides, and inorganic arsenic.[25]

Both EPA and the environmental groups monitoring the agency's actions under section 112 have concentrated on pollutants suspected of causing cancer.[26] The focus on carcinogens creates a dilemma for the agency because many scientists believe that there are no thresholds for carcinogens — no exposure levels short of zero that are risk free.[27] Thus, a strict interpretation of section 112's requirement to provide "an ample margin of safety" would require zero-discharge standards, tantamount to banning the listed substances.

Such a strict interpretation of section 112 could be impractical. Many substances subject to regulation under section 112 are important industrial chemicals. Zero-discharge limitations on these substances would lead to numerous plant closures and the loss to consumers of many valuable products.[28] Consequently, EPA has avoided a strict interpretation of section 112 and instead has proposed standards requiring the degree of control achievable with the "best available technology" (BAT).[29] Standards promulgated by the EPA for asbestos and vinyl chloride illustrate the agency's dilemma and its eventual decision to base control requirements on technological feasibility.

In 1971, EPA proposed standards for asbestos because of its link to a form of cancer known as asbestosis.[30] Public comments on the proposed standards revealed no scientific doubt about asbestos hazards, but also stressed the importance of asbestos to the economy.[31] Although the EPA maintained that the final standard "was not based on economic considerations"[32] and that "the overriding considerations are health effects,"[33] the preamble to the standard acknowledged the dilemma:

24. 40 C.F.R. §§ 61.20–.34, 61.50–.55 (1979) (promulgating emission standards for asbestos, beryllium and mercury); 40 C.F.R. §§ 61.60–.71 (1979) (promulgating emission standards for vinyl chloride).

25. 42 Fed. Reg. 29,332 (1977) (listing benzene as a hazardous air pollutant); 44 Fed. Reg. 76,738 (1979) (listing radionuclides as a hazardous air pollutant); 48 Fed. Reg. 33,112 (1983) (listing inorganic arsenic as a hazardous air pollutant).

26. *See* Statement by W. Ruckelshaus, Administrator of the EPA, Before the Subcomm. on Health & the Env't of the House Comm. on Energy & Commerce 10 (Mar. 29, 1984) [hereinafter cited as 1984 Statement by Ruckelshaus].

27. *See* Industrial Union Dept. v. American Petroleum Inst., 448 U.S. 607, 624 (1980).

28. 1984 Statement by Ruckelshaus, *supra* note 26, at 13.

29. As discussed in more detail below, a "generic" policy proposed in 1979 would have formalized the agency's implicit policy of requiring, at a minimum, BAT controls for sources emitting pollutants listed under section 112. *See infra* text accompanying notes 43–50.

30. 40 C.F.R. §§ 61.20–.25 (1971).

31. 38 Fed. Reg. 8820, 8822 (1973).

32. *Id.*

33. 40 C.F.R. §§ 61.20–.25 (1971).

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> EPA considered the possibility of banning production, processing, and use of asbestos or banning all emissions . . . into the atmosphere, but rejected these approaches . . . . Either approach would result in the prohibition of many activities which are extremely important; moreover, the available evidence relating to the health hazards of asbestos does not suggest that such prohibition is necessary to protect public health.[34]

The effect of this dilemma on EPA action is indicated by the fact that the agency did not even adopt this compromise standard until 1973 (well beyond the 180-day limit), and then only after a court order.[35]

The language of the vinyl chloride standard, promulgated in October 1976,[36] provides an even clearer indication of the adoption of a technology-based approach. In the proposed regulation, EPA interpreted section 112 as allowing it to set standards:

> that require emission reduction to the lowest level achievable by use of the best available control technology in cases involving apparent non-threshold pollutants, where complete emission prohibitions would result in widespread industry closure and EPA has determined that the cost of such closure would be grossly disproportionate to the benefits of removing the risk that would remain after imposition of the best available control technology.[37]

Thus, although section 112 mentions only health effects, and a literal reading might require that all emissions of non-threshold pollutants be banned, the EPA developed an accommodation that bases control on technological feasibility.

EPA did not identify guidelines for listing substances under section 112 in its standards for asbestos or vinyl chloride. Asbestos and vinyl chloride presented clear cases of proven carcinogens, but over fifty other substances are identified only as potentially hazardous air pollutants.[38] In contrast, many toxic water pollutants were listed (and a schedule for developing regulations established) in 1976 as part of a consent decree with the Natural Resources Defense Council.[39]

Environmental groups became dissatisfied with the slow pace at which the agency was listing substances and promulgating standards under section 112.[40] In November 1977, the Environmental Defense Fund

34. 38 Fed. Reg. 8820, 8822 (1973).

35. *Id.*

36. 40 C.F.R. §§ 61.60–.71 (1976).

37. 40 Fed. Reg. 59,534 (1975).

38. 44 Fed. Reg. 58,642, 58,643 (1979).

39. Natural Resources Defense Council v. Train, 8 Env't Rep. Cas. (BNA) 2120 (D.D.C. 1976).

40. *See, e.g.*, Doniger, *supra* note 23, at 565–85 (discussing the politics underlying EPA's promulgation of a vinyl chloride standard).

(EDF) filed a petition requesting that EPA establish the terms of the vinyl chloride agreement as a generic approach to the regulation of all carcinogens.[41] Finally, in October 1979, EPA proposed a cancer policy entitled "Policies and Procedures for Identifying, Assessing, and Regulating Airborne Substances Posing a Risk of Cancer."[42] Although the proposed policy was never promulgated, a review of its provisions provides an indication of the procedures that evolved over the first decade of section 112's existence.

C. Cancer Policy

The most important features of the EPA's proposed "cancer policy" involved the criteria for listing substances and the criteria for setting standards for source categories.[43] The proposal established a relatively low hurdle for listing; EPA would list any substance having a high probability of carcinogenicity unless there was no evidence of a significant threat of ambient exposure from emissions by stationary sources.[44] Upon listing, a set of generic regulations including maintenance, storage, and "housekeeping" requirements would immediately apply to sources emitting the substance.[45]

For each listed substance, the EPA would prepare detailed estimates of health effects and use those estimates to set priorities to develop emission standards for individual source categories posing the most imminent threat to the public health.[46] The emission standards would, at a minimum, require BAT controls. The procedures for determining BAT do not involve risk assessment. Quantitative risk estimates would, however, be employed in the standard-setting process if they showed that the residual risk after BAT controls was "unreasonable." In such a case, EPA would impose tighter controls.[47]

41. *See* Doniger, *supra* note 23, at 584.
42. 44 Fed. Reg. 58,642 (1979). The proposal was part of a larger effort by the Carter administration to develop regulatory policies for carcinogens. A controversial cancer policy proposed by the Occupational Safety and Health Administration (OSHA) preceded the EPA document, *see* 45 Fed. Reg. 5002 (1980). In addition, the heads of the four major regulatory agencies dealing with carcinogens had formed the Interagency Regulatory Liaison Group. That group had a mandate to develop a greater scientific consensus on cancer risk assessment procedures. *Id.* at 58,647. Finally, in 1979 EPA was developing regulations on benzene emissions under section 112 to be used as a prototype for the procedure the agency was elaborating in its generic policy. Indeed, when the White House Regulatory Analysis Review Group selected the EPA cancer policy for review, the agency suggested that the group use benzene as an indicator of how the policy would be implemented. *See* Nichols, *The Regulation of Airborne Benzene*, in INCENTIVES FOR ENVIRONMENTAL PROTECTION 148 (T. Schelling ed. 1983).
43. *See* 44 Fed. Reg. 58,642 (1979).
44. *Id.* at 58,654.
45. *Id.* at 58,648. *See also* 44 Fed. Reg. 58,662–70 (1979).
46. 44 Fed. Reg. 58,642, 58,654 (1979).
47. *Id.*

In sum, EPA's record in implementing section 112 has consisted of much study and little regulation. The proposed cancer policy did create a methodology that would have allowed vastly greater listings, but would also have severely limited EPA discretion in setting specific standards for listed substances.[48] In the last several years, the EPA has continued to analyze potential section 112 pollutants, but has not listed any new substances, nor proposed new standards for substances previously listed, nor promulgated standards proposed earlier.[49] The following statement made by David Patrick, the chief of the Pollutant Assessment Branch in the Office of Air Quality Planning and Standards at EPA, illustrates the concerns of the agency:

> All have perceived that a literal interpretation of section 112 would not preclude open-ended control requirements or the possibility of zero emission goals, regardless of the control costs. Given this potential and the apparent lack of flexibility regarding the removal of substances from the list of hazardous pollutants or the exclusion of source categories from control requirements, the Agency has also been reluctant to list pollutants as hazardous without some reasonable assurance that subsequent regulations would convey health benefits that are not grossly disproportionate to the costs of control.[50]

D. Recent Congressional Debate

In the current debate on reauthorization of the Clean Air Act, environmental groups have criticized EPA's review process as "slow and repetitive."[51] The Environmental Defense Fund has urged Congress to: (1) adopt a generic method for listing airborne carcinogens; (2) list the thirty-seven substances now under study; and (3) require that EPA develop a systematic regulatory approach that includes literature reviews, periodic reports, and time limits for action.[52] In contrast, the Chemical Manufacturers Association (CMA) advocates modifying section 112 to allow EPA to regulate only those substances that pose a significant risk to health and to consider social, technical, energy, and economic consequences in setting standards.[53] Finally, EPA Administrator Ruckelshaus advocates a regulatory strategy that is based on the balancing of

48. *See supra* text accompanying notes 45–47. *See also* Harrison, *supra* note 4, at 112–13.
49. *See* [14 Curr. Dev.] ENV'T REP. (BNA) 1109–11. *But see infra* notes 216–220 and accompanying text (discussing the recent developments in regulation under Section 112).
50. *See* D. Patrick, Air Toxics: Regulation and Research 3 (Apr. 6, 1982) (speech presented at the Air Pollution Control Association (APCA) Conference, Houston, Tex.). *See also* Harrison, *supra* note 44, at 112–13 (critiquing EPA's proposed cancer policy).
51. D. Doniger, Statement on Behalf of the National Clean Air Coalition, Before the Subcomm. on Oversight & Investigations of the House Comm. on Energy & Commerce 10 (Nov. 7, 1983).
52. Doniger, *supra* note 23, at 579–84.
53. [11 Curr. Dev.] ENV'T REP. (BNA) 1026 (1981).

many factors including the nature of the risk posed by a substance and the cost of eliminating or minimizing it.[54]

The eventual result of this debate over section 112 cannot yet be determined. Thus far, however, sentiment in the House seems to favor swifter, more aggressive regulation of airborne carcinogens. In August 1982, the House Energy and Commerce Committee voted in favor of an amendment requiring that, in each of the next four years, EPA review twenty-five percent of the thirty-seven substances discussed earlier.[55] The amendment would create a presumption in favor of listing; each of the thirty-seven substances would be listed automatically unless EPA determined that it was not hazardous.[56] If this provision, or a similar one, is enacted, the pace of regulation under section 112 should reach substantially higher levels than ever before.

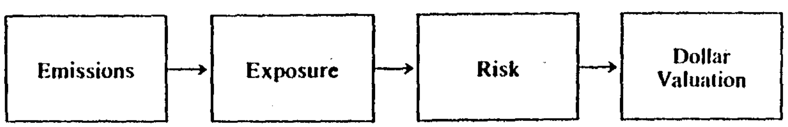
II. The Case Studies

A. *Steps in Estimating Benefits*

These studies estimate the benefits of pollution control standards by tracing the links from emissions to exposure to risk. The purposes of the analysis are either to estimate the dollar value that affected parties place on the reduced risk or to use the risk estimates to calculate the implicit cost per statistical life saved. The steps used, presented schematically in Figure 1, apply in assessing the benefits of controlling virtually any dangerous pollutant. The following discussion provides a general overview of the calculations associated with each step in the context of regulating airborne carcinogens.

The change in emissions due to regulation is the most straightforward of the calculations that produce benefit estimates.[57] For each plant, the

Figure 1: Steps in Estimating Benefits



54. 1984 Statement by Ruckelshaus *supra* note 26, at 14.
55. [13 Curr. Dev.] Env't Rep. (BNA) 491 (1982).
56. *Id.*
57. *But see infra* notes 141–51 and accompanying text (discussing the uncertainties inherent in this analysis).

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EPA estimates the emissions with and without controls in place.[58] The difference between these two estimates equals the emissions reduction attributable to the regulation imposed.

Emissions reduction estimates are converted into more meaningful estimates of exposure reductions by calculating an "exposure factor" for individual plants.[59] The exposure factor indicates the amount of exposure caused by a unit of emissions from a particular source.[60] Both the dispersion pattern of emissions and the population pattern in the area surrounding the plant contribute to calculating this factor.

In many cases, EPA estimates emissions dispersion using a "model plant."[61] For a given level of emissions, the dispersion model uses meteorological data to generate estimates of average annual pollutant concentrations at various distances from the source. The estimated concentrations are then combined with plant-specific population data to estimate total exposure levels for a given level of emissions.

Exposure levels are expressed in terms of "$\mu g/m^3$-person-years," which is simply the average annual concentration (in micrograms per cubic meter) multiplied by the number of people exposed and the period of exposure.[62] This summary measure of exposure provides sufficient information to predict total risk under certain conditions.[63] Dividing the exposure level by the total level of emissions gives the exposure factor, expressed in terms of $\mu g/m^3$-person-years per kilogram emitted.

Reduced exposure is translated into reduced risk using the unit risk factor for the particular pollutant. A unit risk factor represents the risk of cancer posed by exposure to one unit of a substance — measured as the risk of cancer per $\mu g/m^3$-person-year.[64]

Each of the three case studies used unit risk estimates prepared by EPA's Carcinogen Assessment Group (CAG). The CAG unit risk estimate measures the increased probability of cancer resulting from exposure to 1 $\mu g/m^3$ for a lifetime.[65] This figure divided by seventy equals the risk of

58. *See* Office of Air Quality Planning & Standards, U.S. Envtl. Protection Agency, Benzene Emissions from Maleic Anhydride Industry — Background Information for Proposed Standards, Table 1-5 (Feb. 1980 draft) [hereinafter cited as Benzene Emissions Background Information].
59. If a plant with an exposure factor of 0.6 $\mu g/m^3$-person-years/kg reduces its emissions by 1 million kilograms, for example, exposure falls by 0.6(1,000,000) = 600,000 $\mu g/m^3$-person-years.
60. See Nichols, *supra* note 42, at 187–88.
61. *See, e.g.*, Benzene Emissions Background Information, *supra* note 58, at E-8.
62. Thus, for example, 1000 people exposed, on average, to 10 $\mu g/m^3$ for one year generate 10,000 $\mu g/m^3$-person-years of exposure, as do 10,000 people exposed to 1 $\mu g/m^3$.
63. Such risk is independent of how total exposure is distributed across the population if risk is proportional to exposure. *See infra* notes 164–171 and accompanying text.
64. The risk of getting cancer obviously varies with the carcinogenicity of the substance. *See infra* notes 164–183 and accompanying text (discussing the difficulties of extrapolating from low to high doses).
65. CAG considers a lifetime to be seventy years; hence, in this study the CAG's estimated exposure factor is divided by seventy to obtain an annual estimate. *See, e.g.*, Carcinogen Assessment Group, Office of Health & Envtl. Assessment, U.S. Envtl. Pro-

cancer per $\mu g/m^3$-person-year. In applying epidemiological data, the CAG employs a procedure that assumes that risk remains proportional to dose at low levels of exposure.[66]

Over the past decade or two, a substantial literature has accumulated on the issue of valuing reductions in risks to life.[67] Economists agree that the appropriate criterion is "willingness to pay."[68] The principle is a simple one: an individual values each benefit just as much as the amount he would be willing to pay to secure it.

Inferences drawn from actual behavior provide the best estimates of willingness to pay. Many studies have estimated willingness to pay for reduced risks to life based on the wage premiums associated with occupational risks.[69] Bailey has reviewed several empirical studies, adjusting them for consistency.[70] His estimate covers a range of $170,000 to $715,000 per life saved, with an intermediate estimate of $360,000 in 1978 dollars, or approximately $500,000 in 1982 dollars.[71] Other studies, however, have estimated much higher wage premiums for occupational risks, with the highest estimates in excess of $5 million per life saved in 1982 dollars.[72] Thus, the published estimates from wage studies range from several hundred thousand dollars to several million dollars per statistical life saved.

Many of the calculations in this article forgo the final step of placing a dollar value on lives saved and presenting a single net benefit result. However, estimates of the reductions in lives saved and the implicit cost per statistical life saved are presented. These results are then compared

tection Agency, Carcinogen Assessment Group's Final Report on Population Risk to Ambient Benzene Exposures 12 (1977) [hereinafter cited as Final EPA Benzene Assessment].

66. *Id.* at 2.

67. *See, e.g.*, Zeckhauser, *Procedures for Valuing Life*, 23 PUB. POL'Y 419 (1975); Graham & Vaupel, *Value of a Life: What Difference Does it Make?*, 1 RISK ANALYSIS 89 (1981).

68. *See* Schelling, *The Life You Save May Be Your Own*, in PROBLEMS IN PUBLIC EXPENDITURE ANALYSIS 127, 142–58 (S. Chase ed. 1968). Schelling is generally credited with being the first to argue that willingness to pay for risk reduction is the appropriate conceptual approach to valuing "life saving." A slightly different formulation, which should yield virtually identical results when dealing with small risks, is to ask how much money an individual would have to receive to forgo the benefit.

The technical terms for these two measures are "compensating variation" (CV) and "equivalent variation" (EV). In general, when discussing risk reductions, EV (how much money an individual would have to receive to be willing to go without the risk reduction) will exceed CV because of income effects. For small changes in risk, however, the differences between the two measures will be negligible.

69. *See* Thaler & Rosen, *The Value of Saving a Life: Evidence from the Labor Market*, in HOUSEHOLD PRODUCTION AND CONSUMPTION 265–301 (N. Terleckyj ed. 1976); G. Blomquist, Valuation of Life: Implications of Automobile Seat Belt Use (1977) (Ph.D. dissertation, University of Chicago); A. Dillingham, The Injury Risk Structure of Occupations and Wages (1979) (Ph.D. dissertation, Cornell University).

70. *See* M. BAILEY, REDUCING RISKS TO LIFE at app. 35–45, 52–66 (1980).

71. *Id.* at app. 66 (Bailey's estimates are based on Thaler & Rosen, *supra* note 69; Blomquist, *supra* note 69; and Dillingham, *supra* note 69).

72. *See* Viscusi, *Labor Market Valuations of Life and Limb: Empirical Evidence and Policy Implications*, 26 PUB. POL'Y 359 (1978).

with reasonable estimates of the value of this risk reduction to determine if the regulation is likely to pass a benefit-cost test.

B. The Case Studies

Benzene, coke oven emissions, and acrylonitrile are all high-priority section 112 pollutants. Benzene has been listed formally[73] and regulations have been proposed,[74] and recently re-proposed, for several source categories.[75] Coke oven emissions and acrylonitrile are included in a list of thirty-seven substances the EPA is currently evaluating.[76] The health risks of and control options for these pollutants are well documented.[77] Although the following case studies use a common underlying methodology to estimate the benefits of controls for all three pollutants, the empirical details of the methodology vary considerably with each pollutant.

This section presents the results of benefit-cost analysis in each of the three case studies. The next sections suggest two approaches as alternatives to uniform BAT standards: (1) modification of the uniform standards to increase net benefits and (2) differential standards based on exposure levels around individual plants.[78]

1. Maleic Anhydride (Benzene) Case Study[79]

Maleic anhydride plants emit benzene, a major industrial chemical used in making nylon, plastics, insecticides and polyurethane foams.[80] A 1977 study by the National Institute of Occupational Safety and Health showed an abnormally high incidence of leukemia in workers exposed to benzene while employed at two plants in the rubber industry.[81] Following this study, the EPA listed benzene under section 112.[82]

73. 42 Fed. Reg. 29,332 (1977).

74. 45 Fed. Reg. 26,660 (1980).

75. 49 Fed. Reg. 8386 (1984).

76. D. Patrick, *supra* note 50, app. on *Section 112--The Process and Status*.

77. *See, e.g.*, Office of Health & Envtl. Assessment, U.S. Envtl. Protection Agency, Health Assessment Document for Acrylonitrile (Mar. 1982) (draft) [hereinafter cited as Acrylonitrile Assessment Document].

78. *See infra* notes 114–40 and accompanying text.

79. Maleic anhydride plants convert benzene into maleic anhydride — a crystalline cyclic acid anhydride used chiefly in manufacturing resins and modified drying oils. The primary source of data for this case study is Benzene Emissions Background Information, *supra* note 58. For additional sources, see Nichols, *supra* note 42.

The analysis is based on data available to EPA when it proposed the standard for maleic anhydride plants in April 1980. Since then, however, several new developments have led EPA to propose the withdrawal of the proposed benzene control standards. *See infra* text accompanying notes 216–18.

80. *See* S. Mara & S. Lee, Assessment of Human Exposure to Atmospheric Benzene 21 (May 1978) (report prepared by SRI International for U.S. Envtl. Protection Agency) [hereinafter cited as Human Exposure to Benzene].

81. *See* Infante, *Leukemia in Benzene Workers*, 2 LANCET 76 (July 9, 1977). *See also* Nichols, *supra* note 42, at 149–50 (summarizing the studies of benzene's health effects).

82. 42 Fed. Reg. 29,332 (1977). After listing the pollutant, EPA commissioned studies

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In April 1980, almost three years after listing benzene, EPA proposed an emission standard for maleic anhydride plants that use benzene as a feedstock.[83] The BAT standard called for an emissions reduction of roughly ninety-seven percent from uncontrolled levels.[84] A majority of the plants, however, already had installed controls of ninety percent or better, probably in response to state regulations directed at hydrocarbons or the hope that the benzene recovered would pay for the controls.[85] As a result, the proposed BAT standard was expected to reduce full-capacity emissions by less than ninety percent, from 5.6 million kilograms per year to just under 0.5 million kilograms per year.[86]

The costs of implementing the proposed standard were estimated at $2.6 million per year in 1982 dollars.[87] These costs are quite affordable to the maleic anhydride industry, whose total sales grossed $142 million in 1979.[88] The cost estimates are meaningless in isolation, however; they can be judged appropriately only in relation to the benefits they secure. As estimated, the proposed regulations would have reduced exposure by 3.6 million $\mu g/m^3$-person-years and saved 0.4 lives annually.[89]

2. *Coke Oven Emissions Case Study*[90]

Coke, produced by distilling coal in ovens, is essential to the production of iron and steel. In 1978, U.S. plants produced approximately

of benzene emissions. *See* PEDCo Environmental, Inc., Atmospheric Benzene Emisssions (Oct. 1977) (report submitted to U.S. EPA) (EPA-450/3-77-029) [hereinafter cited as Atmospheric Benzene Emissions]; S. Mara & S. Lee, Human Exposures to Atmospheric Benzene (Oct. 1977) (report prepared by Stanford Research Institute for U.S. EPA); Human Exposure to Benzene, *supra* note 80. These studies provided a rough idea of the relative amounts of pollution contributed by different types of sources. *See also* Nichols, *supra* note 42.

83. 45 Fed. Reg. 26,660 (1980). EPA developed an emission standard for maleic anhydride plants first, because more than half of all estimated emissions from chemical manufacturing plants came from the eight plants that used benzene to produce maleic anhydride. *See* Atmospheric Benzene Emissions, *supra* note 82, Table 1-2.

84. The standard limited existing plants to 0.3 kg of benzene emitted per 100 kg of benzene input. 45 Fed. Reg. 26,669 (1980).

85. *See* Benzene Emissions Background Information, *supra* note 58, Table 1-5.

86. 45 Fed. Reg. 26,660, 26,661 (1980).

87. *Id.* at 26,666. *See also* Benzene Emissions Background Information, *supra* note 58. For the two plants that had 90% controls, however, the cost estimates assume that they would need all-new control equipment; no credit is given for possible adaptation of existing controls. All of the cost estimates are for carbon absorption controls, which the EPA estimates indicated would be the lowest-cost control technique (including a credit for benzene recovered), and all assume 100% capacity utilization.

88. *Facts and Figures for the Chemical Industry*, CHEMICAL AND ENGINEERING NEWS 26, 31 (June 13, 1982). The costs estimates included credits for the benzene recovered.

89. *See* Haigh, Harrison & Nichols, *supra* note 12, at 25–28.

90. The primary sources for the coke oven emission case study are: Emission Standards & Eng'g Div., Office of Air Quality Planning & Standards, U.S. Envtl. Protection Agency, Preamble and Regulation for Coke Oven Emissions from By-Product Coke Oven Charging, Door Leaks, and Topside Leaks on Wet-Coal Charged Batteries 1 (Mar. 1981)

44 billion kilograms of coke.[91] Epidemiological studies of coke-oven workers show that emissions from the coking process increased the risks of lung, trachea, bronchus, kidney, and prostate cancers.[92] Although the toxic elements include gases and respirable particulate matter, most attention has focused on the polycyclic organic matter (POM) contained in coal tar particulates.[93]

Coke oven emissions are released from numerous fugitive sources, including leaks and imperfections in the ovens. Charging emissions occur when coal is added to the ovens at the beginning of the coking process. Door leaks are the result of imperfect fits between the ovens and the doors through which the finished coke is later removed. Finally, imperfect seals on the lids and offtakes on the tops of the ovens create topside leaks.[94]

If the EPA listed coke oven emissions under section 112, the Agency would probably specify standards similar to the following as BAT: twelve percent of doors visibly leaking; three percent of lids visibly leaking and six percent of offtake systems visibly leaking; and sixteen seconds of visible emissions for each charging.[95] EPA estimates suggest that only thirty-seven of the fifty-four identified coke plants would have to increase control efforts to meet these standards (and some of those plants already meet one or two of the three potential BAT standards).[96] EPA estimates annual control costs for those plants at $24.5 million.[97]

Plant-specific emission estimates indicate that coke oven emissions would fall by 289,000 kg/year and exposure would fall by approximately

(draft) (Research Triangle Park, N.C.) [hereinafter cited as 1981 EPA Draft Coke Oven Regulation]; Office of Air Quality Planning & Standards, U.S. Envtl. Protection Agency, Coke Oven Emissions from By-Product Coke Oven Charging, Door Leaks, and Topside Leaks on Wet-Coal Charged Batteries — Background Information for Proposed Standards (July 1981) (draft) (Research Triangle Park, N.C.) [hereinafter cited as 1981 Background Information]; Carcinogen Assessment Group, Office of Health and Envtl. Assessment, U.S. Envtl. Protection Agency, Carcinogen Assessment of Coke Oven Emission (Feb. 1982) (draft) (EPA-600/6-82-003) [hereinafter cited as EPA Coke Oven Assessment]; and Research Triangle Institute, Cost Estimates of Meeting the Potential EPA Regulation Affecting Coke Oven Emissions from By-Product Coke Oven Charging, Door Leaks, and Topside Leaks on Wet-Coal Charged Batteries (Apr. 1983) (computer printout) [hereinafter cited as 1983 Research Triangle Cost Estimate].

91. *See* 1981 Background Information, *supra* note 90, at 3-2.

92. *See, e.g.*, EPA Coke Oven Assessment, *supra* note 90, at 108–12.

93. *Id.* at 54–63.

94. 1981 EPA Draft Coke Oven Regulation, *supra* note 90, at 4.

95. *Id.* at 4–5.

96. A detailed breakdown of the status of individual plants is not available. The cost data supplied by the Research Triangle Institute, the primary EPA contractor for the coke oven analyses, includes positive entries only for those plants that are expected to require controls if standards are promulgated. Personal communication from Phillip Cooley of Research Triangle Institute (Aug. 1983).

97. 1983 Research Triangle Cost Estimate, *supra* note 90. EPA's emission and cost estimates are stated in terms of 1982 dollars and assume current compliance with existing state and OSHA regulations. *Id.*

819,000 μg/m³-person-years if the above BAT standards were imposed.[98] Coke oven emissions are very potent carcinogens; this relatively slight reduction in exposure would save an estimated 10.6 lives each year.[99]

3. *Acrylonitrile Case Study*[100]

Acrylonitrile is an important industrial feedstock, employed primarily in the production of chemicals used to make a wide range of common products including rugs, clothing, plastic pipes, and automobile hoses.[101] Almost a billion kilograms of acrylonitrile were produced in 1981.[102] Extensive evidence indicating acrylonitrile's carcinogenicity exists.[103] Specifically, epidemiological studies have associated acrylonitrile with respiratory cancers.[104]

While EPA has neither listed acrylonitrile nor proposed specific regulations, EPA contractors have identified available control options that could reduce emissions by at least ninety-five percent from uncontrolled levels.[105] All thirty existing plants, however, already have implemented some type of controls. Thus, potential BAT standards would only cut annual emissions from 3.6 million kilograms to 0.5 million kilograms, a reduction of slightly less than eighty-seven percent.[106] Uniform controls

98. Haigh, Harrison & Nichols, *supra* note 12, at 32–34.

99. EPA Coke Oven Assessment, *supra* note 90, at 144–63. *See also infra* Table 1.

100. The acrylonitrile case study relied on data assembled from several sources, including Click & Moore, Emission, Process and Control Technology Study of the ABS/SAN Acrylic Fiber, and NBR Industries (Apr. 1979) (report prepared by Pullman Kellogg for the Office of Air Quality Planning & Standards, U.S. EPA, contract 68-02-2619); Key & Hobbs, Acrylonitrile (Nov. 1980) (report prepared by IT Enviroscience for the Office of Air Quality Planning & Standards, U.S. EPA); Energy & Envtl. Analysis, Inc., Source Category Survey for the Acrylonitrile Industry (July 1981) (draft report prepared for the Office of Air Quality Planning & Standards, U.S. EPA, under contract 68-02-3061); Radian Corporation, Locating and Estimating Air Emissions from Sources of Acrylonitrile (Dec. 1982) (draft report prepared for Office of Air Quality Planning & Standards, U.S. EPA); Carcinogen Assessment Group, Office of Health & Envtl. Assessment, U.S. Envtl. Protection Agency, The Carcinogen Assessment Group's Carcinogen Assessment of Acrylonitrile (Feb. 1982) (draft) [hereinafter cited as EPA Acrylonitrile Assessment]; B. Suta, Assessment of Human Exposure to Atmospheric Acrylonitrile (Aug. 1979) (report prepared by SRI Int'l for U.S. EPA) [hereinafter cited as 1979 Assessment of Exposure to Acrylonitrile]; B. Suta, Revised Assessment of Human Exposure to Atmospheric Acrylonitrile Using Industry Supplied Emission Estimates (1982) (report prepared by SRI Int'l for U.S. EPA); and personal correspondence from B. Suta (Aug. 1982) (data on exposure to acrylonitrile emissions) [hereinafter cited as Suta Data on Acrylonitrile].

101. Energy and Envtl. Analysis, Inc., *supra* note 100, at 3-1.

102. *Facts and Figures for the Chemical Industry*, CHEMICAL AND ENGINEERING NEWS 30, 37 (June 14, 1982).

103. EPA identified three epidemiological studies; seven lifetime laboratory studies with rats; several mutagenicity studies with bacteria, Drosophila (fruit flies), and rodents; chromosomal studies of humans; and numerous metabolic studies. Carcinogen Assessment Group, Office of Health & Envtl. Assessment, U.S. Envtl. Protection Agency, Health Assessment Document for Acryolnitrile 101 (1982).

104. *See* EPA Acrylonitrile Assessment, *supra* note 100, at 1, 63–67.

105. *See* Key & Hobbs, *supra* note 100, ch. V, at 1–4, ch. VII, at 1–3 (discussing such control systems).

106. These calculations of emission reductions are based on "current" emissions in

would create an estimated annual expense of almost $29 million in 1982 dollars.[107] Reduced exposure to acrylonitrile, just over 450,000 μg/m³-person-years, would avoid only one case of cancer every five years (0.2 lives per year).[108]

C. *Analysis of the Best Available Technology Standards*

Table 1 summarizes the results of the BAT standards analyzed. Controls on coke oven emissions produce much greater health benefits than do controls on the emissions of benzene or acrylonitrile. BAT controls on coke ovens would result in almost eleven fewer cases of cancer each year, compared to reductions of 0.4 cancer deaths for maleic anhydride benzene controls and 0.2 cancer deaths for acrylonitrile standards.

The final line of Table 1 presents the most relevant figure in measuring the cost-effectiveness of the three control standards — the value placed on saving a life that is necessary to justify incurring control costs. To justify acrylonitrile controls on benefit-cost grounds, the value of a statistical life would have to be at least $144 million, an implausible figure from virtually any perspective.[109] The cost-effectiveness figure for benzene, $6.5 million, also is larger than the range of plausible estimates. Controls on coke oven emissions are the most attractive of the three BAT options. To justify the coke oven emissions standards on benefit-cost grounds, the value of a life saved must be equal to or greater than $2.3 million. That value does fall within the range of the published benefit estimates. Nevertheless, all three BAT options would fail a conventional benefit-cost test based upon a value of $1 million per life saved.

Table 2 indicates two principal reasons why the cost-effectiveness of control varies so greatly among the pollutants. First, the carcinogenic potency of coke oven emissions is much greater than for acrylonitrile or for benzene.[110] Second, coke oven emissions affect many more people than do the other pollutants. Fugitive coke emissions occur at ground

U.S. Envtl. Protection Agency, Summary of Acrylonitrile Emission Estimates and Production Capacities (Jan. 1983) (draft) (tables provided by R. Crume, Office of Air Quality Planning & Standards), and on model-plant controlled emissions in Key & Hobbs, *supra* note 100, ch. V, at 1–4 for AN monomer and in Click & Moore, *supra* note 100, at 61–64. *See also* Haigh, Harrison & Nichols, *supra* note 12, at 36–38.

107. The control costs are estimated from model plant data in Key & Hobbs, *supra* note 100, at Table VI-2, and new plant data in Energy and Envtl. Analysis, Inc., *supra* note 100, at Table 5-5 for AN monomer and in Click & Moore, *supra* note 100, at Table 6-1, for the other categories. All costs have been updated to 1982 dollars using the GNP implicit price deflator. *See also* Haigh, Harrison & Nichols, *supra* note 12, at 36–38 and Table 2.11.

108. *See* Haigh, Harrison & Nichols, *supra* note 12, at 36–41. Exposure factors were estimated using dispersion modeling results and plant-specific population data provided in Suta Data on Acrylonitrile, *supra* note 100.

109. *See supra* notes 67–72 and accompanying text.

110. *See infra* Table 2 (indicating carcinogenic potency with unit risk factors). *See also supra* notes 64–66 and accompanying text.

Table 1: Benefits and Costs of BAT Standards

	Benzene[a]	Coke Ovens	Acrylo-nitrile
Annual Costs and Benefits			
Control Cost ($1000)	2,577	24,511	28,988
Number of plants	8	37	31
Reduced Emissions (1000 kg)	5,059	289	3,112
Reduced Exposure (1000 $\mu g/m^3$-person-yrs)[b]	3,646	819	455
Lives Saved[c]	0.4	10.6	0.2
Cost-Effectiveness			
Emissions ($/kg)	0.51	84.8	9.3
Exposure ($/$\mu g/m^3$-yr)	0.71	29.9	63.7
Lives saved ($1 million/life)	6.5	2.3	144.

Notes:

a. Estimates are based upon the 1980 proposed standard for maleic anhydride plants.

b. Exposure reductions are calculated by aggregating the concentration changes for people at different distances from each plant. For example, if 1000 people have their exposure reduced by 10 micrograms per cubic meter ($\mu g/m^3$) in a given year, exposure would be reduced by 10,000 $\mu g/m^3$-person-years.

c. Lives saved are calculated by multiplying the exposure reduction by a unit risk factor that measures the increased probability of contracting cancer as a result of exposure to 1 $\mu g/m^3$ for one year. For example, if exposure is reduced by 1000,000 $\mu g/m^3$-per-years for a carcinogen that increases the risk of cancer by 1.5×10^{-4} for each $\mu g/m^3$-per-year, a total of 15 statistical lives would be saved. (Note: this article assumes that all cancer cases result in premature death.)

level rather than from stacks, and coke plants tend to be located closer to large population concentrations.[111] As a result, a kilogram of coke oven emissions causes three times the exposure that a kilogram of benzene emitted from maleic anhydride plants does and over seventeen times the exposure that a kilogram of acrylonitrile does.[112] Because of these two factors, a reduction of one kilogram in coke oven emissions produces a risk reduction roughly 500 times greater than for either of the other cases.[113]

Together, tables 1 and 2 indicate that concentrating only on the cost per kilogram of emission reduction provides a misleading measure of the relative attractiveness of the three BAT standards. A kilogram of coke oven emissions is much more costly to control than a kilogram of either acrylonitrile or benzene. The marginal benefit of controlling coke oven emissions is so much larger, however, that coke ovens are far more cost-effective objects of regulation. This comparison gives the most compelling reason for formally evaluating the benefits of toxics control. It is impossible to target controls where they provide the greatest health benefits without considering relative carcinogenicity and relative exposure factors.

111. *See infra* Table 2 (comparing population figures across the three case studies).

112. *Id.* (comparing average exposure factors across the three case-study pollutants).

113. *Id.* (comparing risk per kilogram of emissions across the three case-study pollut

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Table 2: Risk and Exposure Information for the Three Cases

	Benzene[a]	Coke Oven Emissions	Acrylonitrile
Unit risk factor (deaths/ $\mu g/m^3$-yr)[b]	1.1×10^{-7}	1.3×10^{-5}	4.4×10^{-7}
Total population exposed[c]	8,080,000	25,948,000	8,457,000
Population within 1 km	27,550	90,193	7,138
Average exposure factor ($\mu g/m^3$-person-yrs/kg)[d]	0.721	2.83	0.146
Risk per kg of emissions	7.9×10^{-8}	3.7×10^{-5}	6.4×10^{-8}

Notes:

a. Estimates are based upon the 1980 proposed standard for maleic anhydride plants.

b. See footnote c, Table 1.

c. Population within 20 km of all plants.

d. The exposure factor is calculated by dividing the reduced exposure by the reduced emissions. For example, the calculation for coke oven emissions is: 819,000 $\mu g/m^3$-person-years divided by 289,000 kg, which equals 2.83.

D. Analysis of Alternate Standards

Benefit-cost criteria assist policymakers in evaluating regulatory alternatives beyond uniform BAT standards as well. This section analyzes two alternatives for each pollutant: (1) a relaxed uniform standard; and (2) a set of differential standards that would be more stringent for plants located in more densely populated areas than for plants that cause less exposure.

Choosing the appropriate degree of control is a common issue in pollution regulation.[114] Controls should be tightened as long as the marginal benefits exceed the marginal costs. Negative net benefits at one control level do not imply that regulation is undesirable at all levels, because a less stringent alternative may provide positive net benefits.

Pollution control regulations can also be targeted to specific firms.[115] The EPA and other regulatory agencies typically develop regulations for

114. E. Stokey & R. Zeckhauser, A Primer For Policy Analysis 139-42 (1978).

115. *See* Harrison & Nichols, Benefit-Based Flexibility in Environmental Regulation (Apr. 1983) (Discussion Paper Series, Kennedy School of Government, Harvard University) (discussing the general advantages of these differential standards and an evaluation of potential obstacles). The potential policy considerations that might arise in imposing different standards on different plants, including equal protection issues and problems arising from regulations that encourage businesses to locate new plants in less populated but generally more pristine areas, lie beyond the scope of this article.

Table 3: Benefits for Alternative Strategies

	Benzene[a]	Coke Ovens	Acrylonitrile
Percentage of BAT Results			
Relaxed Uniform Standard[b]			
Benefits	94	80	62
Costs	57	61	29
Differential Standard[c]			
Benefits	96	81	60
Costs	37	33	18
Cost per Life Saved (in $1 million)			
Relaxed Uniform[b]	3.9	1.8	64.2
incremental BAT	41.6	4.7	274.
Differential[c]	2.5	0.93	42.1
incremental BAT	80.4	8.3	286.
Net Benefits ($ million/year)			
BAT	−2.2	−13.9	−28.8
Relaxed uniform	−1.1	−6.4	−8.0
Differential	−0.6	0.5	−4.9

a. Estimates are based on data available to EPA when the standard was proposed.
b. Defined as:
maleic anhydride: 90 percent
coke ovens: doors only
acrylonitrile: AN monomer and nitrile elastomer plants
c. Defined as:
maleic anhydride: 97 percent control for plants with exposure factors greater than 0.6
coke ovens: doors and topside for plants with factors greater than 2.0
acrylonitrile: BAT controls for AN monomer and nitrile elastomer plants with exposure factors greater than 0.2

broad source categories. Section 112 is typical; the BAT standards apply to all plants within the source category. This approach ignores the fact that plants located in high density areas affect many more people and produce much greater exposure reduction for the same amount of emission control.[116]

Table 3 summarizes the application of these alternate regulatory strategies to the three pollutants. Alternatives that target controls on the high-exposure plants are referred to as "differential standards." Both the relaxed standards and the differential standards reduce costs much more than they reduce benefits. The cost-per-life-saved estimates, however, are still quite high. In fact, the only alternative that yields positive net benefits at a value per life saved of $1 million is differential standards for coke oven emissions. The other alternatives result in net losses ranging

116. The maleic anhydride plant located in St. Louis, for example, accounts for approximately 80% of the overall benefits. *See* Haigh, Harrison & Nichols, *supra* note 12, at 27.

from $0.6 million for differential standards for maleic anhydride plants to $28.8 million for the BAT standards for acrylonitrile plants.

The wide range in net benefits demonstrates the need for more detailed analysis of alternative regulatory strategies for the specific pollutants. In addition, the details of estimating the benefits and costs of alternatives differ considerably among specific pollutants. Since the analysis of the effect of uncertainty presumes a familiarity with the derivation of the estimates, a more comprehensive description of the case study results is presented below.

1. Benzene

Of the five maleic anhydride plants that would need new control equipment to meet a ninety-seven percent control standard, two already achieve ninety percent control.[117] Therefore, the marginal cost of increasing control efficiency in these plants by seven percent is quite high. EPA would save a substantial amount of money with little change in benefits by relaxing the standard to a ninety percent control level. The estimated exposure reduction is only six percent lower than at ninety-seven percent, but costs fall forty-three percent.[118] The cost per statistical life saved drops to $3.9 million, a substantial improvement over the BAT proposal. The cost per statistical life saved of BAT standards rises to $41.6 million when ninety-seven percent controls are compared to ninety percent controls. Therefore, unless the value of a statistical life saved is taken as greater than $41.6 million, the stricter standard is unjustified.[119]

A uniform standard of ninety percent control improves cost-effectiveness by screening out plants for which the proposed standard has little impact on emissions or exposure. Differential standards, which set tighter requirements for plants with high exposure factors, offer a more ambitious and controversial way of increasing efficiency.[120] In extreme form, differential standards based on exposure factors lead to plant-specific standards. Limited categorization is a more practical approach. The eight plants emitting benzene, for example, could be split into four "high-exposure" plants and four "low-exposure" plants.[121] A regulation requiring ninety-seven percent controls on only the high-exposure plants, and no additional controls on the other plants, yields ninety-six percent of the benefits of the proposed uniform standard at thirty-seven percent of its cost.[122] The differential standard also surpasses the uniform ninety

117. *See* Benzene Emissions Background Information, *supra* note 58, at Table 1-5.
118. *See* Haigh, Harrison & Nichols, *supra* note 12, at 28–29. Unfortunately, the EPA has not developed cost estimates for 90% controls. A conservative estimate of the net benefits of relaxing the standard results from assuming that 90% controls would cost just as much as those achieving 97% for the three plants that currently have no controls.
119. *Id.*
120. *See generally* Harrison & Nichols, *supra* note 115 (discussing the advantages of varying standards in response to inter-plant differences in the marginal benefits of emission control).
121. *See* Haigh, Harrison & Nichols, *supra* note 12, at 29–30.
122. *Id.*

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percent alternative, achieving slightly greater benefits at seventy-one percent of the cost.[123] Thus, even a crude, two-level differential standard significantly improves the cost-effectiveness of benzene standards.[124]

2. *Coke Oven Emissions*

The EPA could improve the cost-effectiveness of BAT controls on coke oven emissions by eliminating controls on some sources of emissions.[125] Controls on charging are substantially less cost-effective than those for doors or topside leaks.[126] Eliminating the charging standard reduces costs by twenty-nine percent, but cuts benefits by only nine percent. Controls on door leaks are the most cost-effective component of the BAT standard, with a cost-effectiveness ratio of less than $1.8 million per statistical life saved. By imposing BAT standards solely on door leaks, the EPA would cut costs thirty-nine percent while retaining eighty percent of the benefits of the complete BAT standard.[127]

A total of fifty-four plants would be subject to BAT control requirements, but seventeen plants currently meet the requirements.[128] The exposure to coke oven emissions varies widely across the remaining thirty-seven plants, with the exposure factor ranging from a low of 0.58 to a high of 5.93.[129] The wide range in exposure factors offers an opportunity to increase efficiency by restricting the standard — or portions of it — to plants with relatively high exposure factors. Of the thirty-seven plants, twenty-one have exposure factors greater than 2.0 $\mu g/m^3$-person-years/kg.[130] A regulation imposing the door and topside standards only on those plants yields eighty-one percent of the benefits at only thirty-three percent of the cost of the uniform BAT standard.[131]

3. *Acrylonitrile*

The thirty plants currently emitting acrylonitrile can be divided into four source categories: AN Monomer, acrylic fiber plants, nitrile elasto-

123. *Id.*

124. Of course, the cost-effectiveness of the differential standards will vary with the categorization of the "high exposure" plants. *Id.* at 31.

125. Although the data available to the EPA permit consideration of the individual components of the BAT standard for coke oven emissions, it is insufficient to analyze alternative levels for the different sources within plants.

126. *See* Haigh, Harrison & Nichols, *supra* note 12, at 34–35.

127. *Id.* The door standard still does not yield positive net benefits, however, unless the value ascribed to saving a life is at least $1.8 million (based again on the CAG risk estimate). *Id.*

128. *See id.* at 16 (citing U.S. EPA, Draft Tables on Maximum and Minimum Emission Estimates from By-Product Coke Oven Charging, Door Leaks, and Topside Leaks on Wet-Coal Charged Batteries (Apr. 1983)).

129. *See id.* at 33 (citing 1981 Background Information, *supra* note 90, at app. E).

130. *See* 1983 Research Triangle Cost Estimate, *supra* note 90.

131. *See* Haigh, Harrison & Nichols, *supra* note 12, at 35–36.

mer, and ABS/SAN resin plants.[132] The cost-effectiveness estimates vary widely among these source categories. A regulation restricting the BAT standards to the two most cost-effective source categories, the nitrile elastomer and AN monomer plants, would yield sixty-two percent of the benefits of the complete set of standards at twenty-nine percent of the cost.[133] The average cost per life saved, however, would still be over $64 million.[134] Controls on even the most cost-effective category, nitrile elastomer plants, yield a cost per life saved of almost $48 million. Thus, none of the BAT standards for controlling acrylonitrile emissions can be justified on benefit-cost grounds.

EPA model plant data indicate that a flare to control column-vent emissions from AN monomer plants would reduce emissions about seventy-six percent below uncontrolled levels at a cost of less than $0.032 per kilogram of acrylonitrile.[135] Using the average exposure factor for those plants of 0.248 $\mu g/m^3$-person-years/kg, the implicit cost per life saved would be under $290,000, a relatively modest sum.[136] All of the AN monomer plants, however, already have such flares.[137] This fact affords at least one indication that manufacturers have already installed those control devices that are least expensive.

As in the other two case studies, widely varying exposure factors offer opportunities to improve cost-effectiveness by limiting standards to high-exposure plants.[138] Regulations restricting BAT standards to AN monomer and nitrile elastomer plants with exposure factors greater than 0.2 $\mu g/m^3$-person-years/kg, for example, yield sixty percent of the benefits of the complete set of BAT standards at only eighteen percent of the cost.[139] The most cost-effective plant, however, has a cost-effectiveness ratio of approximately $18 million per life saved.[140] Thus, although

132.

Plants in the last three categories all use AN monomer as a feedstock. The largest feedstock use is acrylic fibers, employed primarily to manufacture rugs and clothing. ABS and SAN are both resins used to produce hard plastics for such items as pipes, appliances, disposable utensils, and packaging. Nitrile elastomer is a type of rubber used extensively in the automobile industry for hoses, gaskets, and seals.

Id. at 17–18. *See also* Energy and Envtl. Analysis, Inc., *supra* note 100, at 1-1 to 1-9.

133. *See* Haigh, Harrison & Nichols, *supra* note 12, at 39–40.

134. *Id.*

135. *See* Key & Hobbs, *supra* note 100, Table VI-2.

136. *See* Haigh, Harrison & Nichols, *supra* note 12, at 39–40.

137. *See* Key & Hobbs, *supra* note 100, at app. F, at Table F-1.

138. Another possibility is to consider less stringent regulations for the individual source categories. The EPA, however, has not analyzed such alternatives.

139. *See* Haigh, Harrison & Nichols, *supra* note 12, at 40–41. The estimated reduction in emissions from controlling those plants is 312,000 $\mu g/m^3$-person-years, while the estimated control cost is $8.4 million.

140. *Id.* The estimated reduction in exposure from controlling that plant is 98,000 $\mu g/m^3$-person-years, while the estimated cost is $800,000.

differential standards substantially improve the cost-effectiveness ratios of acrylonitrile controls, they do not yield benefits commensurate with the costs of control.

E. Summary

The results of the three case studies indicate that uniform technology-based controls have vastly different net benefits depending upon the pollutant and the source category. The implicit cost per life saved by BAT standards varies by a factor of almost 100 among the three pollutants. Moreover, in each of the three cases, alternate standards yield higher net benefits than BAT for any plausible value of risk reduction. For two of the three cases, however, even the most cost-effective standards considered fail any reasonable benefit-cost test. In the third case, coke oven emissions, regulation produces positive net benefits for a value per life saved of $1 million only by relaxing the control standard and restricting it to high-exposure plants.

These conclusions must be viewed as tentative, for they do not take into account the substantial uncertainties associated with estimating the benefits of controlling airborne carcinogens.

III. Uncertainties in Estimating Benefits

The benefit estimates discussed in the case studies employ point estimates of parameter values based on EPA data. Most of the estimates, however, are highly uncertain; the plausible range for the unit risk estimate in each case covers several orders of magnitude. Critics argue that such uncertainties render quantitative analysis too unreliable to guide policy. The key issue, however, is not whether the estimates are precise — clearly they are not — but how robust the conclusions are in the face of substantial uncertainties and potential errors. This Part evaluates each of the four steps in benefit estimation, beginning with the estimation of emission reduction. It addresses both the generic problems and specific examples from the case studies for each step. Additionally, it considers the potential importance of non-cancer control benefits that have not been quantified.

A. Uncertainties in Estimating Emissions

In theory, estimating emission reductions involves nothing more than monitoring the pollutant source before and after control, and subtracting the results. Despite this apparent simplicity, estimates of the reduction in emissions are far from precise. Several sources of uncertainty, common to the vast majority of regulations likely to be considered under section 112, arise in measuring emissions. In the case of coke oven controls, emissions estimation may be the largest source of uncertainty in estimating the benefits of regulation.

The uncertainties in estimating emissions and emission reductions are particularly great at the level of individual plants. The EPA bases its emission estimates on a model plant and projects them to actual individual sources using a limited number of plant-specific factors.[141] In each of the three cases, for example, EPA assumed that all plants within a given category had the same uncontrolled emission rate. In reality, however, plants are likely to vary widely. An EPA contractor estimated that maleic anhydride plants vary by a factor of three in the amount of benzene that is not converted in the manufacturing process, and that would thus be emitted in the absence of controls.[142] Nitrile elastomer plants emitting acrylonitrile show a similar range.[143]

Another factor creating uncertainty in model plant projections is the lack of adequate knowledge about the effectiveness of existing controls. Although many plants already have emission controls of some kind, due to state regulations, Occupational Safety and Health Administration (OSHA) standards, or economic self-interest in recovering valuable feedstock or by-products, the EPA has made only rough estimates of the effectiveness of such controls.[144]

Finally, model plant estimates do not consider the effects of varying production levels on eventual emissions. Emissions depend on both the emission rate and the percentage of plant capacity used.[145] Few plants operate at full capacity; thus, benefit estimates must be adjusted downward to compensate for actual production levels. This problem is most severe when control techniques are capital-intensive because control costs are then fixed across all production levels while benefits vary directly with production levels.[146] Therefore, the EPA model plant projections may be highly inaccurate predicters of emission reductions at actual plants.

Even if emission estimates are accurate at the time they are made, they may not provide reliable projections of the impact of a proposed regulation. The effects are most dramatic in the case of maleic anhydride plants, where all of the uncontrolled plants identified by EPA when the regulation was proposed have since closed, switched feedstocks, or installed controls.[147] In the case of coke ovens, the depressed state of the

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141. *See* Nichols, *supra* note 42, at 184–86.

142. Benzene Emissions Background Information, *supra* note 58, at 1-7. *See also*, Nichols, *supra* note 42, at 181.

143. *See* Radian Corporation *supra* note 100, at 43.

144. *See, e.g.*, Benzene Emissions Background Information, *supra* note 58, at Table 1-5 (presenting estimates of current benzene emissions from maleic anhydride plants).

145. Obviously, as capacity utilization declines the production process uses less of the substance and therefore emits less of it.

146. Benefits are proportional to the amount of emissions reduced and the emission reduction is related to the production level. Hence, if production levels drop, so do total benefits. Because capital costs are fixed, the benefit-cost ratio also drops.

147. *See infra* notes 216–218 and accompanying text.

steel industry suggests that additional plants may close over the next few years.[148]

Emission estimates are likely to be most uncertain when each plant has multiple "fugitive" sources (such as leaking doors), as the coke oven case illustrates. An EPA contractor presented minimum and maximum estimates, which vary by a factor of 11 for door leaks, 6.4 for topside leaks and over 300 for charging leaks.[149] The results for coke ovens presented in Part II use a simple average of the minimum and maximum estimates.[150] Substitution of the maximum estimates reduces the cost per life saved by less than a factor of two. Use of the minimum estimates, however, increases the cost per life saved by more than a factor of six for the BAT standard.[151]

Uncertainties about emissions appear to be most important for coke ovens because: (1) the uncertainties are much greater for coke ovens than for either of the other cases; and (2) the coke oven decision is the "closest" one, with cost-effectiveness ratios in the plausible range. Even with the maximum emission estimates, however, it is not clear that the uniform BAT standard yields positive net benefits.

These results suggest that it would be useful to narrow the range of estimates of emissions from coke ovens, particularly if the tentative decision was to proceed with regulation. A plausible benefit-cost case for the BAT standard is possible only if actual emissions are in the upper end of the estimated range.

2. *Uncertainties in Estimating Exposure*

The dispersion models used by the EPA to predict pollutant exposure contain pervasive uncertainties. In particular, critics question the reliability of these models at substantial distances from sources and their ability to predict concentrations indoors, where individuals spend most of their time.

Dispersion models for toxic air pollutants combine source characteristics, like the height and velocity of releases, with meteorological inputs, including wind speed, direction, and turbulence.[152] Although the methodology is straightforward, the accuracy of these dispersion models is uncertain. Model accuracy is difficult to evaluate empirically because, in many cases, measured ambient concentrations at a particular location

148. *See* U.S. Envtl. Protection Agency, Draft Tables on Maximum and Minimum Emission Estimates from By-Product Coke Oven Charging, Door Leaks, and Topside Leaks on Wet-Coal Charged Batteries (Apr. 1983) (provided by S. Grove, Office of Air Quality Planning & Standards).

149. *See, e.g.*, 1981 EPA Draft Coke Oven Regulation, *supra* note 90, at 1. The charging standard under consideration for coke ovens, for example, sets an upper bound on the number of seconds of visible emissions during the charging cycle. *Id.*

150. *See supra* notes 90–99, 125–131 and accompanying text.

151. *See* Haigh, Harrison & Nichols, *supra* note 12, at 61.

152. *See* Benzene Emissions Background Information, *supra* note 58, at 4-11 to 4-17.

are hard to relate to emissions from the individual sources modeled.[153]

The accuracy of the models deteriorates as the distance from the source increases.[154] As a result, dispersion modeling usually is not carried out more than thirty kilometers from the source plant.[155] In theory this truncation introduces a bias, understating total exposure levels. Concentrations at greater distances, however, are typically very low, making the resulting bias very minor as well.[156]

Dispersion models are designed to predict outdoor concentrations, but most people spend the vast majority of their time indoors. Recent studies of "indoor air pollution" suggest that concentrations of pollutants indoors may be very different from those outdoors.[157] Many of these studies, however, have involved pollutants that have indoor as well as outdoor sources.[158] Pollutants emitted solely by outdoor sources will have equal or *lower* average concentrations indoors than those outdoors.[159] Therefore, the use of outdoor concentrations to estimate exposure levels may overstate the benefits of the regulations.

Another source of uncertainty arises from the failure to use plant-specific data in estimating exposure from individual plants. Exposure levels around a particular plant critically depend on whether prevailing winds blow toward or away from densely populated areas. Variables like stack height, exit velocity, gas temperature and local meteorological data also affect actual exposure.[160] None of the case studies, however, used such plant-specific data to calculate exposure factors.[161]

153. C. Miller, Exposure Assessment Modeling: A State-of-the-Art Review (1978) (report prepared for U.S. EPA) (EPA-600/3-78-065).

154. *See* Haigh, Harrison & Nichols, *supra* note 12, at 62–63.

155. *See, e.g.*, 1979 Assessment of Exposure to Acrylonitrile, *supra* note 100, at Table VI-5; Benzene Emissions Background Information, *supra* note 43, at app. E-8. The modeling for maleic anhydride plants was carried out only to 20 kilometers, which may distort comparisons with the other cases. *Id.* To check for possible bias, exposures for coke ovens and acrylonitrile were estimated using data carried out to only 20 kilometers and the results were compared with the original estimates. The comparisons were reassuring: the differences were only 9% for coke ovens and 11% for the acrylonitrile plants. *See* Haigh, Harrison & Nichols, *supra* note 12, at 63.

156. *See, e.g.*, 1979 Assessment of Exposure to Acrylonitrile, *supra* note 100, at Table VI-5.

157. *See, e.g.*, Spengler & Sexton, *Indoor Air Pollution: A Public Health Perspective*, 221 SCIENCE 9 (July 1983) (compiling the various primary studies on indoor air pollutants).

158. *Id.* at 11.

159. *Id.*

160. Greater accuracy could be achieved by using more plant-specific parameters, some of which could be measured with very low decision costs. It would seem particularly easy and cost-effective, for example, to use local meteorological data.

161. *See* 1981 Background Information *supra* note 90, at app. E (extrapolating from Pittsburgh meterological data to all coke oven plants); Benzene Emissions Background Information, *supra* note 58, at app. E, at E-8 (extrapolating from Pittsburgh meterological data to all maleic anhydride plants); 1979 Assessment of Exposure to Acrylonitrile, *supra* note 100, at 26 (basing acrylonitrile results on generalized conditions rather than actual data from any particular area).

Finally, EPA estimates implicitly assume that individuals spend all of their time close to their homes; the population data are based on place of residence.[162] This assumption is accurate for children who attend nearby schools, or for non-working adults who spend most of their time at or near home. It may, however, create larger inaccuracies for adults who work far from their homes. To the extent that concentrations where people work are different from those at home, the exposure factors will be inaccurate. Plants located in areas where more people work than live create higher than estimated exposure levels, but the opposite occurs if plants are located in areas where more people live than work.

Uncertainties about the exposure factors used in these case studies have not been quantified. The uncertainties are greatest, however, at the level of individual plants, because of the failure to use plant-specific values for any parameters other than population.[163] No systematic sources of upward or downward bias are apparent in the case study exposure estimates.

C. Uncertainties in Estimating Risk

Estimating the unit risk factor is the most uncertain step in analyzing carcinogens. Evidence of carcinogenicity typically comes from either high-dose animal studies or from epidemiological studies of workers exposed to relatively high concentrations of the substance. All three of the case studies described above relied on epidemiological evidence of carcinogenicity as the primary basis for risk assessment.[164] Thus, none involves the difficult and controversial task of extrapolating carcinogenicity from animals to humans.[165] Risk estimates in the case studies did, however, require substantial extrapolation from high-dose to low-dose exposure.[166]

The problem of extrapolating from high-dose data to low-dose exposures arises because neither epidemiological studies nor laboratory experiments with animals are capable of detecting low-level risks.[167] Several mathematical models have been developed to perform the necessary extrapolations.[168] Unfortunately, neither current theory nor empirical evidence provides unambiguous support for any one model.[169]

162. *See, e.g.*, Benzene Emissions Background Information, *supra* note 58, at app. E, at E-6.
163. *See supra* notes 152–62 and accompanying text. *See also* Harrison, *Distributional Objectives in Health and Safety Regulation*, in THE BENEFITS OF HEALTH AND SAFETY REGULATION 177–201 (A. Ferguson & E. LeVeen eds. 1981) (estimating exposure to automotive air pollution at work as well as at home).
164. *See supra* note 81 and accompanying text (benzene). *See supra* note 92 and accompanying text (coke ovens). *See supra* note 103 and accompanying text (acrylonitrile).
165. *See* E. CROUCH & R. WILSON, RISK/BENEFIT ANALYSIS 64–68 (1982).
166. These studies often measured risk, however, at doses 1000 or more times higher than the exposure levels affected by the regulation. *Id.* at 114–16.
167. *Id.*
168. *See* Nichols, *supra* note 42, at 164–70 (discussing the various models).
169. *Id.*

Most regulatory agencies, including the EPA, use the "one-hit" model or a variant of it.[170] That model assumes that cancer can be induced by a single "hit" of a susceptible cell by a carcinogen. Thus, the model does not yield a threshold below which there is a zero risk of cancer. At low exposure levels, the predicted risk is proportional to the dose; if the relevant dose is 1000 times lower than that at which the risk was measured, for example, the estimated risk is also 1000 times lower. Because of this property, the "one-hit" model is often called the "linear" model.

It is difficult to tell how much of the linear model's popularity is due to scientific belief in its accuracy as opposed to a value judgment that decisionmakers should be conservative in the face of great uncertainty. In any event, most scientists accept the linear model as providing an upper-bound estimate of cancer risk.[171]

The other models commonly used in estimating cancer risk are convex at low doses; as the dose is reduced, risk falls more than proportionately.[172] Given the same data, these models all predict smaller low-dose risks than the linear model.[173] In fact, when the extrapolation from measured risk covers two or more orders of magnitude, as typically happens in EPA regulation, the other models' estimates may be treated as zero because they are so much lower than the linear model's projections.[174] Thus, regulations to reduce low dose exposure to environmental carcinogens must rest on a belief that the linear model has a significant probability of being correct.

Ideally, experts could assess the probability that each of the possible models is correct, and then use those probabilities to compute an expected dose-response function. Unfortunately, such assessments are not available. If they were, it is likely that the expected dose-response function would be approximately linear at low doses, because the nonlinear models predict such small risks that the linear model component would dominate so long as the probability assigned to the linear model's correctness was nontrivial. Note, however, that the unit risk factor for the expected dose-response function would not be as large as that estimated by the linear model alone; the estimated risk would equal approximately the pure linear estimate times the probability that the linear model is correct. Thus, while it may be reasonable to assume that the expected benefits of control are proportional to the reduction in exposure, estimates of reduced mortality in this article are probably too high, perhaps

170. *See, e.g.*, E. CROUCH AND R. WILSON, *supra* note 165, at 115.
171. In its preliminary report on benzene, for example, the CAG said that the linear model "is expected to give an upper limit to the estimated risk." *See* Carcinogen Assessment Group, Office of Health & Envtl. Assessment, U.S. Envtl. Protection Agency, Carcinogen Assessment Group's Preliminary Report on Population Risk to Ambient Benzene Exposures 1 (1977) (unpublished paper).
172. *See* Nichols, *supra* note 42, at 164–70.
173. *See id.* (providing equations for the various models and an example of their widely different predictions at low doses when estimated from the same high-dose data).
174. *See id.* fig. 7.2, at 168.

by a substantial margin, because they rely exclusively on the linear model.

Even if one accepts the linear model, controversies about the interpretation of epidemiological data make the unit risk estimates uncertain. Exposure levels in epidemiological studies often cause the greatest difficulties because the exposures typically occurred many years earlier when few measurements were made.[175] The controversy surrounding the CAG's risk estimate for benzene illustrates this problem and others that can arise in interpreting epidemiological studies.[176]

The CAG based its unit risk estimate for benzene on data from three epidemiological studies.[177] In each case, it had to make assumptions about exposure and other factors. Many of these assumptions have been criticized for overstating the risk.[178] Two EPA analysts, for example, concluded that the CAG risk estimate was too high by a factor of four.[179] An occupational physician testified that the CAG estimate should have been lower by more than a factor of ten.[180] The differences between these estimates and the CAG's are particularly startling because they were based on the same studies and model.

Disputes about the appropriate dose-response model and the interpretation of highly imperfect epidemiological studies make it impossible to develop unit risk estimates for any of the three substances that can be defended rigorously. The unit risk estimates used in Part II, however, probably reflect an upward bias, primarily because they were derived solely from the linear model.[181]

175. *See* Address by S. Lamm to the EPA in Washington, D.C. (Aug. 21, 1980) (testimony for the American Petroleum Institute at hearings on the proposed standard for maleic anhydride plants) [hereinafter cited as Address by Lamm]; *see also* R. Luken & C. Miller, Regulating Benzene: A Case Study (Sept. 1979) (U.S. EPA unpublished paper).

176. *See supra* notes 80–89 and accompanying text (discussing the cost-effectiveness of benzene).

177. *See* Final EPA Benzene Assessment, *supra* note 65. Studies included: one of workers in two plants using benzene as a solvent to make a transparent film, *see* Infante, *supra* note 81, at 76–78; another of Turkish shoe workers using benzene-based adhesives, *see* Aksoy, *Leukemia in Shoe Workers Exposed Chronically to Benzene*, 44 BLOOD 837 (1974); Aksoy, *Types of Leukemia in Chronic Benzene Poisoning: A Study in Thirty-Four Patients*, 55 ACTA HAEMATOLOGICA 65 (1976); Aksoy, testimony before Occupational Safety and Health Administration, Washington, D.C. (July 13, 1977); and the third of workers in chemical plants using benzene, *see* Ott, Townsend, Fishbeck & Langner, Mortality Among Individuals Occupationally Exposed to Benzene (Exhibit 154) (OSHA Benzene Hearings July 19–Aug. 10, 1977).

178. Critics have raised issues including the CAG's exposure estimates for all three studies, its inclusion of the deaths of two workers not in the original cohort of the Infante study, its failure to exclude workers exposed to other hazardous chemicals in the Ott study, and its estimate of the baseline risk in the Aksoy study. *See* Nichols, *supra* note 42, at 170 (summarizing the criticisms of the CAG study); Address by Lamm, *supra* note 175.

179. *See* R. Luken & C. Miller, *supra* note 175.

180. Address by Lamm, *supra* note 175, at 4.

181. *See supra* notes 170–75 and accompanying text. For benzene, several studies suggest further that the CAG has overestimated the linear model's coefficient. *See supra* notes 176–80 and accompanying text.

To the extent that the unit risk factors are too high, the expected benefits of controls are overestimated. Revising those estimates downward reinforces the earlier conclusions that benzene and acrylonitrile controls are not cost-effective.[182] It also reinforces the conclusion that uniform BAT standards on all three sources of emissions from coke oven plants would not be cost-effective relative to less stringent regulations.[183]

D. Uncertainties in Valuing Risk Reduction

Critics of the use of benefit-cost analysis to evaluate environmental policy often focus on the difficulty of assigning a "value to life."[184] The empirical studies of wage premiums for occupational risk cited in Part II cover a wide range, from several hundred thousand to several million dollars per life saved. Even that wide range, however, is sufficient to reject BAT standards for maleic anhydride plants and for all four types of plants emitting acrylonitrile. It is also sufficient to indicate cost-beneficial modifications of the coke oven regulations, though not sufficiently precise to determine if more limited regulation of coke ovens is justified.

Several objections can be raised to the use of wage premium studies to value risks reduced through environmental regulation. If workers are not fully aware of the risks they run, wage premiums will not reflect the workers true willingness to accept risk in exchange for higher pay.[185] In addition, dangerous jobs tend to be filled by individuals willing to accept risks for lower compensation.[186] Thus, even if the wage premium studies accurately measure trade-offs acceptable to workers studied, they may underestimate the general population's willingness to pay for reduced risk.

Despite these criticisms, some simple examples suggest that the higher end of the range of values estimated by the wage premium studies is more likely an overestimate than an underestimate. If the value per life saved is $5 million, for example, the government should impose auto safety regulations that cut the risk of traffic fatalities in half as long as the control cost per new car is less than $12,500.[187] With that same value

182. *See supra* notes 117–24 and accompanying text. *See also supra* notes 132–140 and accompanying text.

183. *See supra* notes 125–31 and accompanying text.

184. *See, e.g.*, Doniger, *supra* note 23, at 518–19; Rodgers, *Benefits, Costs, and Risks: Oversight of Health and Environmental Decisionmaking*, 4 HARV. ENVTL. L. REV. 191, 196–98 (1980).

185. *See* Raiffa, Schwartz & Weinstein, *Evaluating Health Effects of Societal Decisions and Programs*, in DECISION MAKING IN THE ENVIRONMENTAL PROTECTION AGENCY (1977).

186. *Id.* at 37.

187. As there are roughly 50,000 automobile-related fatalities each year, such a technology would save 25,000 lives annually. If the value per life saved is $5 million, then the value of the technology would be $125 billion. If we assume further that there are 10 million new cars sold each year, then the technology would be worth up to $12,500 per car. *See* Haigh, Harrison & Nichols, *supra* note 12, at 68.

per life saved, a family of four with the median yearly income should be willing to give up about one half of that income in order to face the average overall death rates that prevailed in 1975 rather than those from 1970.[188]

A more fundamental philosophical objection is based on the distinction between voluntary and involuntary risks.[189] Individuals are free to choose their jobs (and their cars). In contrast, people, as individuals, have little choice about the quality of the air that they breathe. Society should be willing to pay much more to avoid such involuntary risks, the argument continues, than individuals would spend to reduce hazards over which they have personal control. Supporters of benefit-cost analysis reply that it makes little sense for the government to make fundamentally different trade-offs than individuals would when confronted with similar private choices.[190] Decisionmakers, however, may be especially concerned about distributional implications if the risks are unusually large and concentrated among a small group of individuals.[191]

Two factors suggest that, in general, a lower value should be ascribed to lives saved through the regulation of environmental carcinogens than to many other public choices involving risk. First, cancer is disproportionately a disease of the elderly, so each life "saved" represents relatively few additional years of life.[192] Regulatory programs should be evaluated in terms of years of life saved, not total lives saved.[193] This suggests that the value per life saved should be lower for evaluating regulations to control carcinogens than for analyzing other programs, such as highway safety, that prevent the deaths of younger people.

The second factor is the substantial delay between control expenditures and reductions in risk due to time lags between exposure to carcinogens and the onset of disease. Conventional benefit-cost analyses discount streams of benefits and costs to reflect the time value of money. Economists differ as to whether discounting should be applied to health

188. *See* Bailey, *supra* note 70, at 45–46.

189. See E. CROUCH AND R. WILSON, *supra* note 165, at 85.

190. *See, e.g.*, Zeckhauser, *supra* note 67, at 419.

191. For a general discussion on distributional effects of environmental regulations, *see* Harrison, *supra* note 163; Harrison and Portney, *Who Loses from Reform of Environmental Regulation* in REFORM OF ENVIRONMENTAL REGULATION (W. Magat ed. 1982). *See also* D. HARRISON, WHO PAYS FOR CLEAN AIR? (1975) (discussing the cost and benefit distribution of federal automobile emission standards).

192. The death rate for the type of leukemia associated with benzene, for example, is more than 26 times higher among people aged 70 to 74 than among children aged 1 to 5. *See* Final EPA Benzene Assessment, *supra* note 65, at Table 1.

193. Zeckhauser and Shepard argue that mortality benefits should be summarized in terms of the discounted number of "Quality Adjusted Life Years" (QALYs) saved. Their QALY measure adjusts benefits to include reductions in the quality of life due to disability, for example. *See* Zeckhauser & Shepard, *Where Now for Saving Lives?*, 40 LAW AND CONTEMPORARY PROBS. 5 (Autumn 1976).

benefits.[194] Most theoretical discussions support discounting,[195] but in common practice the timing issue is ignored.[196]

Discounting reduces the relative value of saving lives through control of environmental carcinogens, because the benefits of reducing exposure are realized many years after the costs are incurred. At a discount rate of five percent, for example, a twenty-year time lag reduces the value of risk reduction by sixty-two percent compared to an immediate risk reduction, say through improved fire protection.[197]

The valuation of risk reduction remains uncertain and highly contentious, with little prospect for agreement on any particular dollar value for saving a life. The problem is at least as much one of ethics and politics as it is one of science and the interpretation of empirical evidence. EPA, however, cannot avoid making trade-offs between protection and control costs, whether it does so explicitly or implicitly. Fortunately, precision may not be very important because many decisions are correct over wide ranges of values. Moreover, it is possible to narrow the range presented earlier by reducing the high end. Values much in excess of $1 million per life saved appear difficult to justify, particularly for airborne carcinogens for which the benefits are delayed and the lives saved are relatively short.

E. Unquantified Benefits[198]

EPA's procedures almost certainly overstate the cancer-reduction benefits of controlling hazardous air pollutants. By focusing solely on cancer in its quantitative estimates for section 112 pollutants, however, the EPA may miss other important health and environmental benefits.

Many carcinogens, including the three considered here, have also been associated with non-cancer health effects at relatively high doses.[199] For most of these non-cancer effects, however, scientists generally accept

194. *See, e.g.*, Raiffa, Schwartz & Weinstein, *supra* note 185, at 42–49.

195. *See, e.g.*, *id.* at 49.

196. *See, e.g.*, Page, Harris & Bruser, Removal of Carcinogens from Drinking Water: A Cost-Benefit Analysis (Jan. 1979) (Social Science Working Paper #230, California Institute of Technology, Pasadena, Cal.).

197. The equation for discounting is $B/(1+r)^x = PV$, where B is the benefit in current dollars, r is the discount rate, x is the number of years from today in which the benefit accrues, and PV is the present value of the benefit. In the example given, r equals .05 and x equals 20; the present value of the benefit today (PV) is 37% of B.

198. This article, and therefore this section, considers only human health benefits; no consideration is given to benefits related to reduced wildlife and plant damage from these toxic substances. *See, e.g.*, Acrylonitrile Assessment Document, *supra* note 77, at 88–100 (describing the effects of acrylonitrile on plants, domestic wildlife and aquatic organisms).

199. Office of Research & Dev., U.S. Envtl. Protection Agency, Assessment of Health Effects of Benzene Germane to Low-level Exposure 48–65 (1978) (EPA-600/1-78-061) (noting benzene's association with aplastic anemia and other serious blood disorders)

the concept of zero-risk thresholds, and current environmental exposures appear to lie far below the relevant levels.[200]

Chromosomal damage — mutagenic effects — may be an exception, as scientists are less willing to assume that such effects have thresholds.[201] All three of the case study pollutants appear to cause chromosomal damage.[202] None, however, has been associated with birth defects, and analyses by EPA's health experts emphasize mutagenic evidence as corroborating the carcinogenicity of the substance, rather than as a separate concern.[203]

The "conventional pollutant" benefits associated with controlling some hazardous air pollutants may be more significant. States have regulated benzene and acrylonitrile to help meet the ambient standard for ozone.[204] Coke ovens have been regulated to meet the particulate ambient standard.[205] In addition, controls on section 112 pollutants may also control other pollutants. If maleic anhydride plants use incineration to control benzene emissions, for example, they would also reduce carbon monoxide, a "conventional" pollutant covered by an ambient standard.[206]

Occupational exposure represents still another potentially important omitted benefit category. Some controls designed to reduce emissions to the ambient environment also reduce the exposure of workers. This effect is most likely to be significant when the emissions are from low-level, fugitive sources, as is true of coke ovens. If the sources are elevated stacks, as with maleic anhydride plants emitting benzene and the acrylonitrile plants, environmental controls are unlikely to have much impact on workers.

The importance of these omitted benefit categories varies widely across specific regulations. In the three cases discussed, they do not affect the basic conclusions for maleic anhydride plants and acrylonitrile, primarily because the cancer benefits are so small in those cases and the

[hereinafter cited as Health Effects of Benzene]; EPA Coke Oven Assessment, *supra* note 90, at 54–63 (noting the acute and chronic toxicity of coke oven emissions); Acrylonitrile Assessment Document, *supra* note 77, at 116–48 (noting the acute, subacute and chronic toxicity of acrylonitrile).

200. *See, e.g.*, Nichols, *supra* note 42, at 152 (benzene).

201. *Id.* at 162.

202. *See* Acrylonitrile Assessment Document, *supra* note 77, at 156–66; Final EPA Benzene Assessment, *supra* note 65, at app. 1–5; EPA Coke Oven Assessment, *supra* note 90, at 27–52.

203. *See, e.g.*, Final EPA Benzene Assessment, *supra* note 65, at app. 1–5.

204. *See, e.g.*, [3 State Air Laws] ENV'T REP. (BNA) 521:0621, 521:0631–:0664 (1983) (Texas' regulation of volatile organic compound emissions); [1 State Air Laws] ENV'T REP. (BNA) 346:0501, 346:0521 (1983) (Florida's regulation of volatile organic compound emissions).

205. *See, e.g.*, [1 State Air Laws] ENV'T REP. (BNA) 301:0501, 301:0513–:0515 (1982) (Alabama's restrictions on coke oven emissions); *id.* at 336:0501, 336:0512 (1984) (Delaware's restrictions on coke oven emissions); [2 State Air Laws] ENV'T REP. (BNA) 411:0501, 411:0516 (1982) (Michigan's restrictions on coke oven emissions).

7 '5 Fed. Reg. 26,660, 26,661 (1980).

only potentially important omitted benefits appear to be those associated with conventional pollutants. To the extent that such benefits are important, benzene and acrylonitrile are probably best addressed by the framework established for other conventional pollutants — state implementation plans for existing sources and new source performance standards for new ones.

The omitted benefit categories are more troubling for the coke oven case, primarily because it is a closer decision on the basis of cancer reduction benefits alone. The quantitative significance of the additional benefits from reduced worker exposure and reduced particulate emissions cannot be evaluated, but it seems unlikely that they would be sufficient to justify the uniform BAT standard over the alternatives of a less stringent uniform standard or a differential stategy targeted at high exposure plants.

F. Summary

Huge uncertainties pervade estimates of the benefits of regulating airborne carcinogens. As a result, the figures presented in Part II must be viewed with a strong dose of skepticism; they may well be in error by orders of magnitude. These uncertainties, however, do not alter the major conclusions of the case studies.

The clearest conclusions emerge for the four source categories emitting acrylonitrile. The cost-effectiveness ratios for emission controls were ten or more times higher than the plausible range of values for risk reduction.[207] Nothing in this section has suggested that benefit estimates err by that margin.[208]

The calculations for benzene emitted from maleic anhydride plants gave a substantially narrower result, although the estimated cost per life saved was still in excess of $6 million.[209] Several factors suggest that an accurate estimate of the expected cost-effectiveness ratio would be substantially higher. They include: (1) the general issue of the appropriate dose-response model;[210] (2) evidence that the CAG overestimated the linear model's risk factor;[211] and (3) a significant rise in the cost per life saved when the estimates are adjusted for less than full capacity operation.[212]

The most ambiguous results arise in the case of coke ovens, although a BAT standard for charging emissions almost certainly would fail a

207. *See supra* notes 132–140 and accompanying text.

208. Unless, of course, one favors a nonlinear dose-response model, but that would cut in the other direction.

209. *See supra* notes 87–89 and accompanying text.

210. *See supra* notes 167–175 and accompanying text.

211. *See supra* notes 176–180 and accompanying text.

212. *See supra* notes 145–146 and accompanying text.

benefit-cost test.[213] Whether the uniform door and topside standards generate positive expected net benefits remains in doubt. Two issues raised in Part III, however, weigh against those standards: (1) the likelihood that the pure linear model overestimates the expected risk;[214] and (2) the evidence suggesting that a value on risk reduction much in excess of $1 million per life saved cannot be justified.[215] In fact, it is unclear whether even differential standards limited to high-exposure coke plants would yield positive net benefits. Such standards, however, unquestionably represent an alternative superior to uniform BAT standards.

G. Postscript

Recent developments reinforce our conclusions regarding benzene emitted from maleic anhydride plants and cast further doubt on the wisdom of imposing standards on coke ovens. After the maleic anhydride standard was proposed in 1980, five important changes took place: (1) four plants shut down; (2) two plants converted to n-butane, apparently in response to higher benzene prices; (3) the largest plant installed controls and began to convert all of its capacity to n-butane; (4) an additional plant was "discovered;" and (5) EPA reduced the BAT standard to the equivalent of ninety percent control.[216] As a result, had the standard been imposed, it would have applied only to the newly discovered plant, a small one located in a lightly populated area, and the estimated health gain would have been to prevent approximately one case of cancer every 300 years.[217] Citing those minimal potential health impacts, the EPA withdrew the proposed standard for maleic anhydride plants in early 1984.[218]

More recent estimates from the EPA indicate that coke oven plants also pose a smaller threat than estimated earlier. Data in a recent EPA report suggest that the BAT standards would save less than five lives per year, in contrast to over ten lives per year estimated on the basis of the earlier data. The newer EPA estimates rely on higher emissions but much lower exposures, based on newer modeling using meteorological data for each plant.[219] Even more recently, the CAG lowered its estimate of unit

213. *See supra* notes 125–127 and accompanying text.
214. *See supra* notes 167–175 and accompanying text.
215. *See supra* notes 67–72 and accompanying text.
216. *See* A. Nichols, Targeting Economic Incentives for Environmental Protection 157 (1984).
217. *Id.*
218. 49 Fed. Reg. 8386 (1984).
219. *See* Office of Air Quality Planning & Standards, U.S. Envtl. Protection Agency, Coke Oven Emissions from Wet-Coal Charged By-Product Coke Oven Batteries — Background Information for Proposed Standards (Sept. 1983) (draft EIS) (Research Triangle Park, N.C.). This document does not calculate reductions in fatalities or exposure. It does, however, include estimates of unit risk and baseline emissions and cancer cases, from which it is possible to measure average exposure per unit of emissions. The document also gives estimates of emission reductions, from which reductions in cancer cases can be estimated.

risk and the EPA learned that additional plants have shut down, so the estimated annual reduction in cancer cases has fallen to about two.[220] It thus appears that coke ovens are no longer a "close" case; although no cost estimates are available for the closed plants, the estimated cost per case avoided for the BAT standards must be well in excess of $5 million.

IV. Findings

The three case studies illustrate many of the problems and uncertainties involved in estimating the benefits of environmental regulation. Although benefit-cost analyses of such regulations can never be very precise, these studies suggest that quantitative assessments of benefits can provide valuable information to regulators interested in improving the efficient use of society's resources. In this Part, some of the lessons from the case studies are summarized, first with respect to section 112 of the Clean Air Act and then with respect to the more general use of benefit-cost analysis to evaluate strategies for regulating health-threatening pollutants.

A. Section 112

In dealing with "hazardous air pollutants" covered by section 112 of the Clean Air Act, the EPA has consistently followed a technology-based approach to regulation. The "generic" policy proposed in 1979 would have formalized this approach in an attempt to speed up and routinize the process of listing and regulating such substances.[221] More recently, some members of Congress have suggested forcing EPA regulation of section 112 pollutants by giving the agency a deadline for making decisions on a list of thirty-seven substances.[222] The BAT approach to regulation is flawed because it implicitly treats airborne carcinogens as a homogeneous class. The case studies indicate that airborne carcinogens are a very heterogeneous class, with wide variations in benefits (and costs) across substances and source categories.

1. Heterogeneity

Even within a small sample of three pollutants studied, the risk reduction benefits from controlling emissions vary enormously because of differences in carcinogenic potencies and in exposure patterns. Each kilogram of coke oven emissions, for example, causes about 500 times as much cancer risk as a kilogram of acrylonitrile or a kilogram of benzene emitted from a maleic anhydride plant.[223] Regulatory analyses that focus

220. Personal communication from Teresa Gorman, Office of Policy, Planning & Evaluation, U.S. Envtl. Protection Agency, Washington, D.C. (Apr. 12, 1984).
221. *See supra* notes 43–50 and accompanying text.
222. *See supra* text accompanying notes 55–56.
223. *See* Haigh, Harrison & Nichols, *supra* note 12, at Table 2.1.

on the feasibility and affordability of controls ignore these critical differences.

The cost per unit of risk reduction also varies greatly across the three cases, differing by a factor of more than 100 between coke plants and the least cost-effective acrylonitrile category. These wide variations suggest that a policy of applying BAT standards to *all* sources emitting airborne carcinogens imposes higher than necessary costs to achieve *any* given level of overall risk reduction. Individual substances and source categories must be considered on their own merits, taking account of potencies and exposure levels as well as technology and affordability.

2. Modest Benefits From Control

The desirability of strict regulations on airborne carcinogens is easily overstated. In both the benzene and the acrylonitrile cases, for example, a small number of sources emit millions of kilograms of proven human carcinogens each year. Moreover, the controls being considered are eminently affordable; their costs are estimated at less than two percent of total sales.[224]

The case studies show, however, that only modest health benefits are likely to result from the regulations. BAT standards for both acrylonitrile and maleic anhydride plants would have a combined effect of avoiding less than one cancer death per year. The coke oven standards would provide substantially larger benefits, but even in that case the gain in public health seems rather modest for standards that apply to a major industry on a nation-wide basis.

Of course, it is not certain that all section 112 regulations would yield similarly small benefits. The case studies, however, cast doubt on the proposition that control of airborne carcinogens will lead to major reductions in the nation's cancer burden. The fact that the pollutants considered here have been assigned relatively high priority by EPA reinforces this skepticism.

B. The Role of Benefit-Cost Analysis

1. Evaluating Proposed Regulations

Existing methods of quantitative assessment may not yield clear answers as to the cost-effectiveness of regulations in all, or even most, cases. Many of the components in benefit estimation are highly uncertain. Because the final estimate typically is a multiplicative function of these individual components, the overall level of uncertainty is extremely high. Nonetheless, robust conclusions often can be drawn to help regulators avoid imposing some regulations for which the benefits are far smaller than the costs. Benefit-cost analyses may also identify regulations that clearly provide positive net benefits, although none of the instant case studies identified such a regulation.

224. *See, e.g., supra* text accompanying notes 87–88.

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2. Improving Regulations

Most discussion of benefit-cost analysis focuses on its role as a "test" for proposed regulations. Benefit-cost analysis is even more useful, however, as a tool for designing regulations. In all three of the case studies, less stringent controls yielded most of the benefits of the BAT standards at far lower cost. Although none of these modified uniform standards resulted in clearly positive net benefits, all were more efficient than the original BAT standards. If benefit-cost principles were applied early in the regulatory process and used to guide the selection of control options for detailed analysis, even larger gains could be realized.

The case studies indicate that regulatory efficiency is maximized by exploiting marginal differences in the benefits of control among sources. These differences arise primarily because of differences in population densities around plants; the public health benefits of controlling emissions are far larger in cities than in lightly populated rural areas. In all three cases, restricting standards to areas where the marginal benefits of control are relatively high led to impressive efficiency gains over uniform standards.

3. Information Requirements and Delays

If they are to be useful to decisionmakers, analytic techniques can not rely on data that are unduly expensive or time consuming to obtain. Analysis is not free; it consumes scarce resources that could be put to other uses and may cause delays in an already lengthy regulatory process. Fortunately, a great deal can be done with information that is already collected by EPA. Also, a sharper set of decision criteria should speed up rather than delay the regulatory process. Note that the technical data for all three case studies were based on information developed as part of EPA's BAT strategy for controlling hazardous air pollutants. Thus, performing the kinds of analyses presented in this article should not significantly increase either the costs or the delays of the regulatory process.

For relatively close decisions, such as the coke oven case, additional information could prove useful, particularly in four areas: (1) cost and emissions estimates for a wider range of control options; (2) more plant-specific data for exposure estimates (as were recently developed by EPA for coke ovens); (3) estimates of non-cancer benefits, particularly those associated with conventional pollutants (such as ozone and particulate matter); and (4) development of techniques for estimating the expected level of cancer as well as the "plausible upper bound" now used by EPA.

Adoption of benefit-cost principles could reduce the amount of information required to regulate in many cases. Current efforts, for example, typically include studies of the "economic impact" of regulations, attempting to predict their effects on plant closings, product prices, and the like. Such impacts are of second-order importance relative to the direct benefits and costs of control. Application of benefit-cost principles in allocating agency resources may also reduce the costs of analysis by leading to the curtailment of the regulatory process before large expenses

have been incurred to gather data. The acrylonitrile case provides an excellent example; some crude analysis early in the regulatory process — based on the unit risk factor, existing levels of control, and average exposure factors — probably would have indicated the minimal potential benefits involved and consequently eliminated the need for detailed analysis of control technologies and costs.

C. Conclusion

Pleas for the use of benefit-cost analysis in environmental decision-making are commonplace. This article contributes to the discussion by illustrating how benefit-cost techniques might be employed to evaluate individual regulations, to identify promising alternatives, and to evaluate the robustness of regulatory choices relative to uncertainties. Although the case studies reviewed here assess particular regulations for airborne hazards, the conclusions regarding the usefulness of benefit-cost principles apply more generally.

Over two dozen federal statutes require the regulation of toxic or hazardous substances.[225] Some of these explicitly call for a balancing of benefits and costs,[226] while others use a "reasonableness" standard that would permit such an analysis.[227] Those statutes that explicitly permit the consideration of only health effects tend to deal with food products or common consumer items.[228] Thus, a benefit-cost analyis, although not applicable to all situations, could be applied far beyond the Clean Air Act.

The advantages of benefit-cost principles must, however, be put into perspective. A benefit-cost analysis of an environmental program is not a substitute for good science or good judgment. To the contrary, explicit estimation of health risks, and the amount that controls will reduce those risks, provides a context for incorporating both science and judgment into regulatory decisions. Cruder rules based solely upon evidence of carcinogenicity or technological feasibility of control hide the real choices involved in regulating health-threatening substances.

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225. Office of Toxics, U.S. Envtl. Protection Agency, Chemical Substances Designation (Dec. 1981).

226. *See, e.g.*, Environmental Pesticide Control Act, 7 U.S.C. §§ 136b(b), 136a(c)(5) (1982); Federal Hazardous Substances Act, 15 U.S.C. § 1262(i) (1982); Toxic Substances Control Act, *id.* § 2605(c) (1982); Food, Drug & Cosmetics Act, 21 U.S.C. § 346a(b)(1) (1982); Atomic Energy Act, 42 U.S.C. §§ 2022(a), 2022(b), 2114(a) (Supp. V 1981).

227. *See, e.g.*, Poison Prevention Packaging Act, 15 U.S.C. § 1472(b) (1982); Hazardous Liquid Pipeline Safety Act, 49 U.S.C.A. § 2002(b) (West Supp. 1983).

228. *See, e.g.*, Food, Drug & Cosmetics Act 21 U.S.C. §§ 342(a)(2)(A), 348(c)(3)(A), 360(d)(1)(H), 376(b)(5)(B), 451, 601, 1031 (1982); Lead Based Paint Act, 42 U.S.C. § 4831 (1976 & Supp. V 1981). Other non-consumer statutes also focus exclusively on health factors. *See, e.g.*, Surface Mining Control and Reclamation Act, 30 U.S.C. §§ 1265(b), 1266(b)(9)(A) (Supp. V 1981), Marine Protection, Research, and Sanctuaries Act of 1972, 33 U.S.C. § 1412(a) (1976).